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M.O. No. 190.

BAROMETRIC GRADIENT AND WIND FORCE.

REPORT

TO THE

DIRECTOR OF THE METEOROLOGICAL OFFICE

ON THE

CALCULATION OF WIND VELOCITY FROM PRESSURE DISTRIBUTION

AND ON THE

VARIATION OF METEOROLOGICAL ELEMENTS WITH ALTITUDE,

BY

ERNEST GOLD, M.A.,
Fellow of St. John's College, Cambridge,
(Superintendent of Instruments).

Published by the Authority of the Meteorological Committee.

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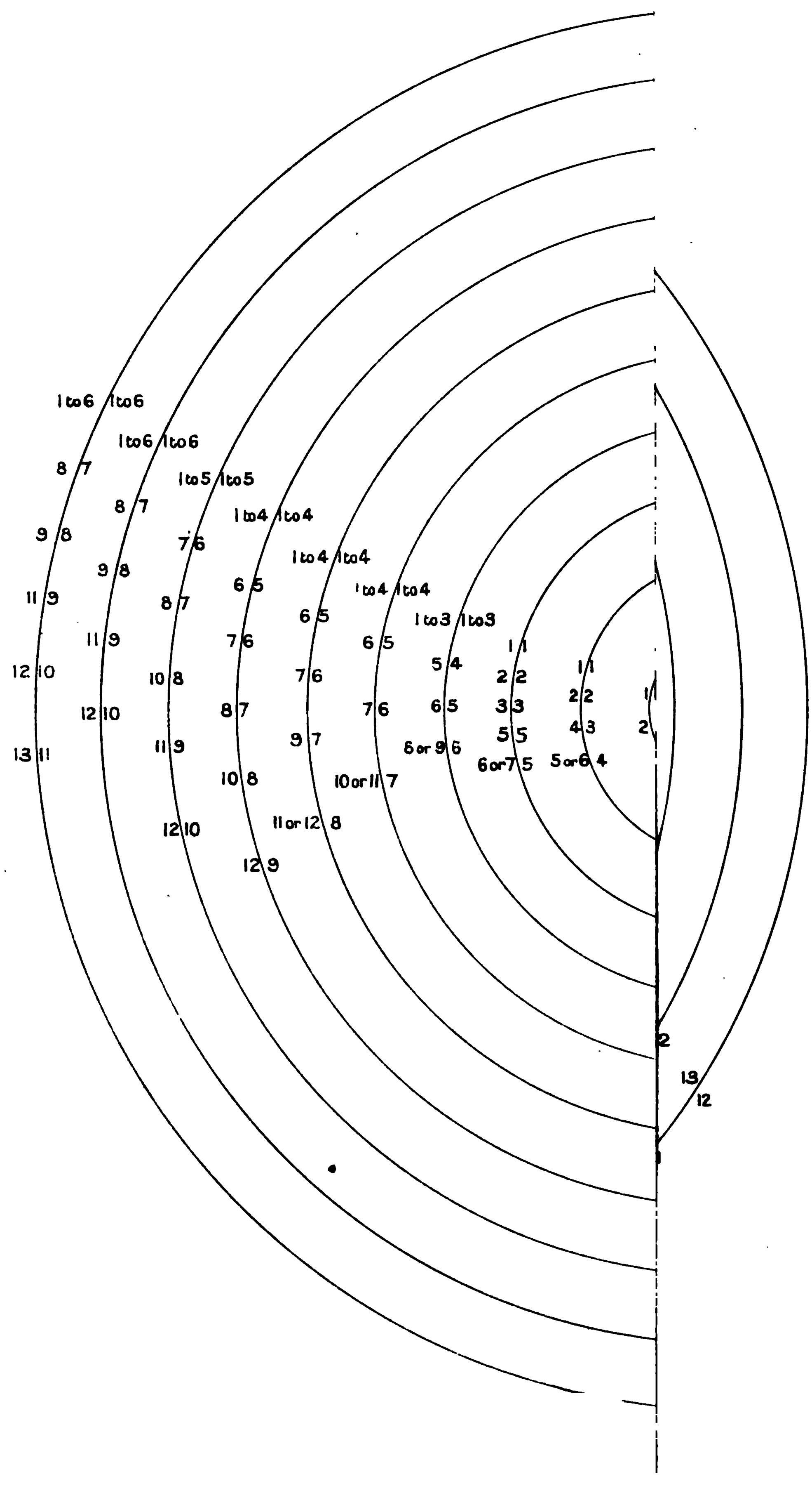

Scale for estimating theoretical wind on Beaufort Scale from the normal distance between $\frac{1}{10}$ in isobars, in Working Charts of the Meteorological Office.

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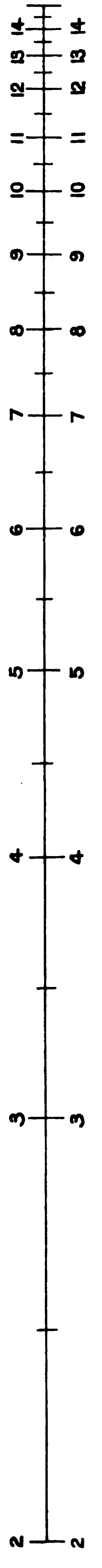

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REPORT

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DIRECTOR OF THE METEOROLOGICAL OFFICE

ON THE

CALCULATION OF WIND VELOCITY FROM PRESSURE DISTRIBUTION

AND ON THE

VARIATION OF METEOROLOGICAL ELEMENTS WITH ALTITUDE.

PREFACE.

The relation of wind force to barometric gradient is a fundamental question in modern meteorology.

From the consideration of the motion of a particle upon a rotating sphere it is easy to imagine conditions under which air may move for an indefinite period without any alteration of its speed. Supposing in the first place that the motion is along a great circle on the Earth, that no deviation from the great circle is to be permitted. The moving air is inevitably subject to a horizontal acceleration, or tendency to move, towards the *right* (in the northern hemisphere) in consequence of the rotation of the Earth. The magnitude of the potential acceleration depends on the latitude and on the numerical product of the speed of the wind and the angular velocity of rotation of the Earth, and if there be a distribution of pressure which gives a resultant push of appropriate magnitude in a direction across the line of motion, to the *left*, it may be adjusted so as to counteract the tendency due to the Earth's rotation, and in that case the motion along the great circle will continue.

But to keep up this state of things for any considerable time it would be necessary for the pressure gradient across the line of the great circle to be always available, constant in relative direction, and adjusted in magnitude to suit the latitude throughout the journey, a state of affairs which is entirely contrary to experience. It would be idle to form a picture of a current of air moving all round the girdle of the Earth, with a persistent coercive force of pressure from right to left of the appropriate magnitude. It would bear only transient and occasional resemblance to actual fact. In practice, as the air moves along the surface, it passes into positions where the pressure gradient is different in direction or in magnitude, or in both, from that experienced at the point of departure, even when allowance is made for change of latitude. If the Earth's rotation alone came into consideration, persistent motion of air, *i.e.*, motion without any considerable change of velocity would hardly come within the purview of practical meteorology.

But there is another way of producing an effect which helps to counteract the pressure gradient, and that is by motion along a curved path. No illustration is more familiar in practical mechanics than the case of a body moving without change of speed in a circle, in consequence of the action of a force which always pushes it towards the centre, but never effects any approach thereto, because of the balance between the so-called centrifugal force of rotation and the centripetal dynamical force which pushes it inwards. The motions of the heavenly bodies, of the Moon round the Earth, of the

Earth with reference to the Sun, differ but little from the motion of a body kept in a circular orbit by the centripetal force of gravitation. Substitute the force of horizontal pressure gradient for that of gravitation, and we find a corresponding illustration in the wind when the air moves in a small circle, as it does approximately in a tropical revolving storm ; the centripetal force of the pressure gradient is nearly balanced by the centrifugal action of the rotation in the small circle.

In the more general case of the moving current of air in temperate latitudes, the motion without change of speed along a curved path, that is along portions of successive small circles on the Earth's surface, demands on its own account a compensating pressure gradient.

We have thus three items which may arrange themselves to maintain motion of air without change of speed, viz., pressure gradient, the Earth's rotation, and the curvature of the path.

It is evident that this extended possibility of bringing about an adjustment between these elements makes the idea of the motion of air over great distances with a constant speed much more practicable. Dynamically all that is necessary for constant speed is that the forces which act upon the moving air shall be perpendicular to the direction of its motion. The horizontal acceleration due to the rotation of the Earth, and that due to the curvature of the path, both comply with that requirement, so neither of them will alter the speed. The persistence of motion with constant speed becomes a question of adjusting the combined effect of the two accelerations to balance the effect of pressure.

The question at once arises whether it is possible, under practical meteorological conditions, that such an adjustment should be automatic ; whether, indeed, by natural process the velocity and the curvature tend to adjust themselves so as to balance the pressure distribution. If that question be answered in the affirmative, a great advance is made in dynamical meteorology. We know then that the actual motion at any time is either the motion with constant speed to which the circumstances tend, or some disturbance of that state, the causes of which must be considered.

The adoption of this idea changes the point of view of the meteorologist very materially. If persistent motion with constant speed, the "gradient velocity," becomes the stable and in a sense the "natural" condition of moving air, we must seek first to explain, not the actual motion, but the divergence of the actual motion from the gradient velocity. The gradient velocity thus becomes the starting point of meteorological study. Although it may not be possible, on account of the fact that we do not always know the path or its curvature, to determine in any particular case the gradient velocity, yet the relation is none the less a real one.

There is at least sufficient evidence to justify the serious consideration of the question. Buys Ballot's law, which takes motion along the isobar as a guide to the direction of the actual motion, is the fundamental law of practical weather study in temperate latitudes, and the calculation of the gradient wind is the subject of classical researches by Guldberg and Mohn.

At the surface there is obviously a serious cause of disturbance in the surface friction to which the authors mentioned have assigned a numerical value. To make a theoretical allowance for the disturbing cause in individual instances is a difficult matter, and for many years that difficulty has prevented the further prosecution of the subject. The working hypothesis of practical meteorology has been that the friction affects both the direction and the speed of the wind, so that the actual velocity can only be a rough and uncertain approximation to the gradient velocity, and the idea of thus treating the motion of air with gradient velocity as a basis of meteorological study has not been developed.

In a work published last year upon the "Life History of Surface Air Currents," Mr. Lempfert and I gave the results of tracing with all the accuracy possible to us, the variation of condition of air as it moved over the surface ; and, as will be seen at once by a reference to the frontispiece of the volume, one of the most obvious conclusions from that research in the kinematics of the atmosphere, is that, as a matter of fact, air in its motion is subject to very little and very slow change of velocity. The meteorological time unit is the hour or the day, and in these intervals the changes of velocity in the moving air are comparatively small, so small indeed that the expression of the force requisite to produce the observed changes of velocity is infinitesimal compared with the forces due to the distribution of pressure displayed upon a weather map.

I once calculated that if the pressure forces were allowed to act upon the air in which they are observed, in the same way as one supposes the forces to act in the calculations of elementary dynamics, they would in one hour produce a velocity of something like 2,000 miles per hour. Such a velocity is entirely outside meteorological experience, and since that time, instead of looking for dynamical forces which produce the ordinary velocities observed, I have been led to regard persistence of the velocity without change, the absence of any rate of change that can be expressed in ordinary figures, as the normal condition of atmospheric motion. We have looked for cases in which there were rapid changes such as might be produced by the unrestrained action of the moving forces. We have found only one case in which such a condition of things seemed at all applicable. We have felt constrained to regard the rapid and automatic adjustment of velocity and curvature to the requirements of the gradient as an effective meteorological law of the first importance.

I have already referred to surface friction as a disturbing cause. There are doubtless others. The wind, as represented upon a pressure tube anemometer for example, is made up of alternate puffs and lulls of short period. In dealing with the relation of wind to gradient the fluctuations of short period are, at present, not considered.

In estimating the gradient wind from the isobaric distribution shown upon a weather map we are met by the difficulty that one of the elements necessary for the calculation, viz., the curvature of the path, cannot be determined as a general rule from a single map. The investigation of air currents to which reference has already been made showed that the path of a portion of air was not represented by an isobar, and in order to determine the path a succession of maps would be required. A reference to the diagrams representing the actual trajectories of air shows that in these islands the paths are generally less curved than the isobars, and in the barometric changes which take place the wind moves more nearly in a straight line on the map than if it followed the direction indicated by the isobar upon which, at any instant, it finds itself. (*See* Mr. Gold's note, p. 42.)

In these circumstances it is difficult to know what allowance should be made for the curvature of the path. We may, however, regard the isobars as representing the paths of air in the limiting case when the motion is tangential and the barometric distribution remains stationary. Such a case is approximated to when a cyclonic depression moves slowly.

The use of isobars as lines of curvature thus gives an extreme value for the correction for curvature in most cases, but, in the absence of any means of determining the actual curvature, the estimation of the limiting value may give useful information about the atmospheric conditions.

There are, undoubtedly, cases in which the observed wind velocity is not in accordance with the gradient as thus calculated from the isobars plotted on a map. I shall refer to these exceptions later on; at present I confine myself to saying that the existence of such exceptions is not surprising; what is remarkable is that they are, comparatively, so few.

The attention of the Office was directed towards the subject again by the request of one of the departments of Government for a formula for the variation of the velocity of wind with height.

Mr. Dines had recently, at my request, added to the kite equipment at Oxshott, a means of measuring the velocities of the wind in the free air; and, on comparing the velocities with the surface gradient velocity, he had found that the agreement between calculated and observed velocity improved, as might be expected, with height above the ground, and that at 1,500 feet there was agreement between the two on the average within 20 per cent. In estimating the gradient velocity Mr. Dines had only used a rough approximation. With modifications to meet special conditions, he had taken the average gradient for a stretch of some 500 miles, and had made no allowance for curvature.

The rough agreement shown was, however, sufficient to indicate that a better estimate of the wind aloft could be obtained by computing the gradient velocity at the surface than by using an empirical formula for the variation of wind velocity with height and applying it to the readings of an anemometer near to the surface. In other words, in the absence of the disturbing cause of surface friction, the automatic adjustment of wind velocity to pressure-gradient was more exactly carried out.

When it became necessary in June, 1906, to supply estimates from time to time of the wind velocities of the upper air upon the basis indicated, Mr. Ernest Gold had joined the Office staff as Superintendent of Instruments. I instructed him to make the estimates of the velocity as the requisitions came in; secondly, to prepare a scale and series of circles for the easy reading off of the gradient velocity from the isobaric charts, and for determining a limiting value for the curvature correction; and, thirdly, to examine the question of the variation of the meteorological elements with height, as disclosed in the reports coming into the Office upon the observations in the upper air by means of kites, which had become an established branch of the operations of the Office, since October, 1905.

In the report now published, Mr. Gold gives an account of the work which he has done upon the subjects indicated. The scale and series of circles are reproduced as the frontispiece to the volume and the tables used in their construction are given on pp. 18–23.

The general result of the investigation is, in my opinion, to confirm the suggestion that the adjustment of wind velocity to the gradient is an automatic process which may be looked upon as a primary meteorological law, the results of which are more and more apparent as the conditions are more and more free from disturbing causes, mechanical or meteorological.

In support of this view I may refer to the important result which Mr. Gold has deduced in a simple manner from the opposition of the two accelerations due to the rotation of the Earth and the curvature of the path respectively, in anticyclonic areas. He has shown that on the assumption that the actual motion of air is to be represented by the automatic adjustment of velocity and curvature to the existing gradient, there is a limiting velocity in anticyclonic areas, and a limiting gradient, depending upon the curvature of the path. If the limit were exceeded the roots of a certain quadratic equation coming into the calculation would become imaginary. It is worthy of remark that the conclusion drawn in this way from the nature of a simple algebraical expression is borne out satisfactorily by the well known facts that the gradient and wind velocity are both light in the central portions of anticyclonic areas where the path, if represented by an isobar, must have considerable curvature, whereas in cyclonic regions any gradient and any corresponding wind are apparently possible.

The hypothesis of the automatic adjustment of velocity and curvature to the gradient thus explains in a simple and adequate manner the characteristic difference which has long been recognised between the winds in the inner regions of anticyclones and cyclonic areas. So far as I know the explanation of these characteristic differences on a dynamical basis is new. Mr. Gold follows these ideas further, and on pp. 13, 14 gives a calculation of the length of time that would be required for air starting from a state of rest to take up the gradient velocity and adjust its motion to the direction of the isobars. The computed times are short compared with such an interval as a day, an ordinary period in meteorological discussion, so that we need not be surprised that, under the slow changes of condition due to the progress of diurnal or of non-periodic changes, the wind appears to adapt itself continuously to these changes.

Further, Mr. Gold has examined in detail the relation between the gradient velocity and the observed direction and force of the wind in the upper air as given by the daily observations of a year at Berlin and Lindenberg. Allowing for the uncertainty of the correction for curvature the agreement of the averages is remarkably close, and fully supports the ideas which have been put forward. Numerically the correction for curvature appears to be somewhat too large, a striking result when one considers that the use of the isobar for calculating the curvature overestimates the correction. I may refer to his report (p. 36) for the justification of the use of the barometric gradient at the surface in the computation of the velocity in the upper air. The errors occasioned thereby are not likely to be serious unless the lower layers of the atmosphere are very heterogeneous in temperature.

If, then, it be admitted that the process of adjustment of velocity to gradient is constantly going on and appears, generally speaking, to have approached completion in the upper air, it behoves us to consider the cases of marked discrepancy beyond the limits of inaccuracy due to our want of knowledge of the curvature. First of all, let me refer to the obvious cases suggested by the comparison of winds at inland stations with those at sea or on exposed coasts. I must remark at once that the means for the determination of the real gradient are very inadequate. The barometric readings are all reduced to sea level, but the winds cannot be. Consequently, we may be comparing things which are not really comparable, and, secondly, the determination of a gradient by means of isobars constructed from observations at stations many miles apart does not show the variations of pressure in sufficient detail. I may quote an actual case which will illustrate my meaning. On August 31st, 1906, at Stornoway, in the Western Hebrides, the weather was fine and sunny, and, from time to time as the day wore on, a south-easterly wind established itself with long periods of steady blow, during which it must have reached force 6 on the Beaufort scale, alternating with periods of comparative lull. The barometer fell about a hundredth of an inch in the periods of wind, and rose again in the periods of lull. Above, the clouds drifted steadily from the west. I was told that the strong wind was only local, and would not be felt outside the harbour. I have reason to think that the view was correct. Such a state of things might be easily explained, if we consider the effect of the sun upon the land. It would produce a temporary low pressure over the land round which in course of time a circulation would be established in the manner indicated by Mr. Gold's calculation. A narrow belt of air moving with a velocity corresponding to force 6 would be a sufficient barrier for preventing the cool air of the sea from flowing on to the land ; the motion would have become tangential instead of radial. Thus we should have, after some hours of sunshine, a steady condition with considerable temperature gradient and consequent pressure gradient on the margin of sea and land. Its steadiness would be promoted by the general calmness of sea and air outside. The motion might be taking place in strict conformity with the local gradient extending over a belt of, say, two miles, but on the map the gradient would have been estimated by comparing the Stornoway pressure with that at Sumburgh Head, Nairn, and Malin Head, some hundreds of miles away. The local gradient over the two miles would not be indicated. Yet the difference of a hundredth of an inch over the two miles would be sufficient to give a gradient at the rate of an inch in two hundred miles, an ample gradient for the observed wind. Cases of the occurrence of gradients over restricted districts are often indicated on our maps (compare the charts for October 3rd, 6 p.m., and 8th, 8 a.m.) ; and between sea and land, under certain conditions of weather, there is the possibility of local differences of pressure which control the observed wind, but which are far too small and too restricted in area to be detected on the daily chart. It is possible that to such restricted areas of pressure gradient may be referred some of the phenomena of local winds which have been unexplained hitherto.

In dealing, therefore, with the discrepancies between the computed and observed winds some allowance must be made for the insufficient means of estimation of the gradient for the exact locality in which the wind is observed. This part of the subject deserves more refined investigation than is possible with the arrangements, instrumental and other, at present in use. At the least, it supports the suggestion put forward by M. Durand-Greville for the drawing of isobars with more scrupulous attention to the individual readings and for small steps of pressure.

But no development in the construction of maps can do away with the effect of surface friction or surface eddies upon the velocity of the moving air current. We do not yet know what is the effect of surface friction over the sea ; it certainly takes a great deal of energy out of the moving air and converts it into the energy of water waves or water currents. Still, it is probably much less than that of the obstruction offered by land. The first effect of a land area upon a current coming from seaward must be partly to arrest the motion and cause some increase of pressure by mechanical means. Such an interference with the free motion of the air must thus produce what may be called a "refraction" of the isobaric lines on the transition between sea and land. This, again, is a branch of the subject to which not much attention has been devoted.

There remain the local peculiarities of contour which deflect the wind by mechanical process in a manner similar to that in which the shape of a valley guides the course of a river or a glacier. There is, of course, every stage of screening possible between the slight interference of a flat spit of sand and the absolute protection of a completely secluded valley; but, so far, the effect of screening upon the direction and force of the wind at any particular station is a matter of speculation. Mr. Gold suggests the formation of a table of relation between observed and calculated wind for individual stations. The suggestion is obviously a useful one, and I hope to get it carried out in the course of time for the British stations. Here I would merely say that the personal estimation of the effect of the surroundings of a station upon its winds is of very limited utility until it is verified by reference to some standard. The reference of the observed winds from various quarters and of various strengths to the gradient winds, affords a scientific method of expressing the characteristics of the station as regards wind.

In carrying out the comparison of wind velocity with gradient velocity for the upper air, we are met with a difficulty suggested by the fact that in the upper air itself the winds of different horizontal layers, or for different isobaric surfaces, differ in direction or magnitude, or in both, and sometimes very considerably. Cases are indeed not uncommon in which an easterly current has a westerly one above it. I have not, myself, noticed any case of sudden transition from one direction or speed to another; all the cases which I have noticed, permit one to suppose there is a gradual change of gradient, but it is still an open question whether the changes which have been observed can be referred to corresponding changes in gradient at the different levels. The question is an interesting one, especially in view of the succession of currents from various directions at different heights disclosed by the researches of Monsieur L. Teisserenc de Bort over the inter-tropical Atlantic.

In order to approach the solution of this question we require to know very precisely the variation of the meteorological elements with height, so that the density of an air column of given height may be properly estimated.

We have not yet arrived at finality in this part of the subject, but as a contribution to our knowledge of the general structure of the atmosphere, I submit the diagrams prepared for me by Mr. Gold, from kite results at Oxshott, Berlin, and Blue Hill.

The method followed in the construction of the diagrams is sufficiently explained in the text.

Reverting again to the question of the gradient velocity, I do not at present offer any suggestion as to the cases in which, when every allowance has been duly made, there is an outstanding discrepancy between the gradient wind and the actual wind. I have, indeed, the sufficient reason that we do not yet know the nature or extent of these discrepancies; but I will mention two points of interest in that connection. First, it is a matter of common knowledge among meteorologists, that when a depression is approaching, it is the backing of the wind that first attracts attention. The barometer begins to fall later. Secondly, M. Guilbert, at the competition at Liege, in 1905, made a number of remarkably successful forecasts, based on the consideration of the "divergence" of the actual winds from the "normal" winds corresponding to the isobars. The normals here mentioned do not correspond with what I have called the gradient winds; the velocities are considerably smaller. I have not yet ascertained how they have been arrived at.

The fact that in the upper air the correction for curvature derived from the isobars over-corrects the estimate, suggests that if one knew the true upper-air-wind, the difference between it and the wind computed from the distance of the isobars would give

London

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whole question of the cause and meaning of the discrepancies between the rind and actual wind is, of course, bound up with the origin of pressure . To put the point in a crude form, I do not know whether, in practice, the e to adjust themselves to the pressure conditions, or the pressure distribution is of the motion of the air. I presume, however, that as a matter of fact, it is a ion and reaction in which each modifies the other. That question still remains gation. The practical conclusion of the present contribution is to show that tend to adjust themselves automatically, so that the wind corresponds with the nd it follows from that, that the cases, whether on the surface or in the upper h there are departures from the correspondence, and which cannot be explained causes, are likely to be productive as a subject of meteorological study.

W. N. SHAW.

rological Office, London,
5th October, 1907.

Meteorological Office,
63, Victoria Street, London, S.W.,
October 1st, 1907.

Sir,

I beg to present the Report you desired on the calculation of the wind from the pressure distribution, and the comparison between the calculated values and those observed in the upper air. I have added an account of the results obtained at Oxshott in 1906, and at Berlin in 1905, by means of kite and balloon ascents.

I am, Sir,
Your obedient Servant,
ERNEST GOLD.

The Director,
Meteorological Office.

BAROMETRIC GRADIENT AND WIND FORCE.

The following paper is divided into two sections. The first deals with the calculation of wind velocities from the distribution of the isobars, according to the theory of Ferrel and Guldberg and Mohn. The second contains an account of the results obtained from kite and balloon ascents in Germany and England, during 1905 and 1906, and a comparison between the values obtained for the wind velocity and direction at 1,000 metres altitude, by experiment and according to calculation.

I.

It is not proposed here to develop further the theory of the relation between atmospheric currents and pressure distribution, but rather to take the formulæ already worked out and put them into such order as shall enable close comparisons to be made between observed and calculated winds. Little seems to have been done in this direction since *Ley and †Loomis carried out their investigations into the relation between the directions of the wind and the gradient, and the application of Ferrel's formulæ to surface winds.

For air moving under a steady pressure system along the isobars, the relation between the pressure gradient and the velocity v, is given by the equation $\frac{1}{\sigma}\frac{dp}{dn} = 2\,\omega\, v \sin\phi$, where σ is the density of the air, p the pressure, n the normal to the isobars, ω the angular velocity of the earth about the polar axis, ϕ the latitude of the place ($\omega = \frac{2\,\pi}{86164} = \cdot 00007292$).

It is clear that a state of affairs in which this formula *is* accurately true, could not be far reaching or persistent, owing to the effect of the variation of latitude, but with a given pressure distribution the formula ought to furnish a first approximation to the velocity for places where friction is negligible, and sin ϕ is an appreciable magnitude.

Immediately a pressure difference arises between two places, the air, if at rest before, will begin to move in the direction of the gradient. As soon, however, as it begins to move the acceleration due to the rotation of the earth will be called into play, and the air will be deflected in a direction perpendicular to its motion. If we assume the pressure to continue steady over a considerable distance, there will come a time when the force due to the pressure gradient and that due to the Earth's rotation balance one another, and keep the air moving along the isobars. The question arises as to whether the pressure is likely, in actual circumstances, to continue steady long enough for such a state of affairs to come about. We can get some idea of the time required to elapse by considering the motion of a particle on the Earth's surface, moving under a constant force in a constant direction.

The equations of motion of a particle referred to axes through a point O in latitude ϕ on the earth's surface, and fixed in the earth are‡

$$\frac{d^2x}{dt^2} - 2\omega\cos\phi\frac{dz}{dt} - 2\omega\sin\phi\frac{dy}{dt} = X.$$

$$\frac{d^2y}{dt^2} + 2\omega\sin\phi\frac{dx}{dt} = Y.$$

$$\frac{d^2z}{dt^2} + 2\omega\cos\phi\frac{dx}{dt} = -g + Z.$$

where the axis of z is the vertical at O and the axes of x and y are taken in a West and South direction.

If there is no vertical motion the first two equations may be written

$$\frac{d^2x}{dt^2} - a\frac{dy}{dt} = X.$$

$$\frac{d^2y}{dt^2} + a\frac{dx}{dt} = Y.$$

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* Quarterly Journal, Royal Meteorological Society, 1876, 1877.

† American Journal of Science 1875, 1879, 1883.

‡ *See* Routh's Rigid Dynamics, Part II., p. 28.

and the form of these equations and the value of a will be unaltered by changing to other axes in the same plane.

Suppose, then, we have a particle moving under a constant force in a constant direction. Let us take the direction to be that of the y-axis. The equations of motion then become

$$\frac{d^2x}{dt^2} - a\frac{dy}{dt} = 0$$

$$\frac{d^2y}{dt^2} + a\frac{dx}{dt} = b.$$

If the particle start from rest, the equations give

$$x = \frac{b}{a^2}(at - \sin at)$$

$$y = \frac{b}{a^2}(1 - \cos at)$$

The time until $\frac{d^2y}{dt^2}$ vanishes is $\frac{\pi}{2a}$ and until $\frac{dy}{dt}$ vanishes is $\frac{\pi}{a}$. The particle moves in a series of curves similar to cycloids.

If we assume the force to be constant in magnitude but directed from a fixed point, it will be more convenient to use polar co-ordinates r, θ instead of x, y. The equations become, if we assume that there is no vertical motion,

$$\frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 = \mathrm{R} + a\frac{rd\theta}{dt}$$

$$r\frac{d^2\theta}{dt^2} + 2\frac{dr}{dt}\frac{d\theta}{dt} + a\frac{dr}{dt} = 0$$

$$\text{whence } r^2\frac{d\theta}{dt} + \frac{1}{2}ar^2 = \text{constant} = \mathrm{B}.$$

If the particle starts from the centre $\mathrm{B} = 0$

$$\therefore \frac{d\theta}{dt} = -\frac{1}{2}a$$

and the solution is

$$r = \frac{4\,\mathrm{R}}{a^2}\left(1 - \cos\frac{at}{2}\right)$$

$$= \frac{4\,\mathrm{R}}{a^2}(1 - \cos\theta)$$

The particle therefore moves in a cardioid.

The time in this case, until the acceleration along the radius vector vanishes, is $\frac{2\pi}{3a}$ and until the velocity in that direction vanishes, is $\frac{2\pi}{a}$.

Taking $a = 2\omega \sin\phi$, the times in hours for the two cases are, for the constant force,

$$3 \operatorname{cosec}\phi \text{ and } 6 \operatorname{cosec}\phi,$$

and, for the radial force,

$$4 \operatorname{cosec}\phi \text{ and } 12 \operatorname{cosec}\phi \text{ ...hours.}$$

For latitude 50°, these times are approximately

4 and 8 hours, and 5 and 16 hours

respectively.

It will be noted that the motion of the particle is in both cases oscillatory, but a very small fractional effect will damp the oscillations.

If, in the case of radial force, the particle starts from rest at a point distant c from the centre, the expression of t in terms of r involves elliptic integrals. There are however values of r for which $\frac{d^2r}{dt^2}$ and $\frac{dr}{dt}$ vanish and we can, by using these approximate in any particular case for the times to these values of r. They are in general less than the values given above.

If the isobars are sensibly curved, and the motion is still steady and along the isobars, the equation connecting the velocity with the gradient takes the form

$$\frac{1}{\sigma}\,\frac{dp}{dn} = 2\,\omega\,v\sin\phi \pm \frac{v^2}{r}$$

where r is the radius of curvature of the path† in a horizontal plane.

If v is expressed in metres per second and x is the normal distance in kilometres between millimetre isobars, the equation may be written, neglecting the effect of humidity on σ

$$v\sin\phi\,(1 \pm v\cot\rho\,\operatorname{cosec}\phi \times {\cdot}00108) = \frac{\mathrm{T}}{\mathrm{T}_0}\cdot\frac{\mathrm{B}_0}{\mathrm{B}}\cdot\frac{709}{x},$$

where T and B are the absolute temperature and barometric pressure of the moving air, T_0 and B_0 the corresponding quantities for air at 0° C. and 760 mm., while ρ is the angle subtended at the centre of the earth by the radius of the small circle on the earth's surface osculating the path of the air.

At the earth's surface T and B differ by relatively small quantities from T_0 and B_0, and the formula may be written

$$v\,(1 \pm v\cot\rho\,\operatorname{cosec}\phi \times {\cdot}00108) = \frac{709\operatorname{cosec}\phi}{x}\;\frac{1 + {\cdot}00366t}{1 + {\cdot}00131b}$$

$$= \frac{709\operatorname{cosec}\phi}{x}\,(1 + {\cdot}00366t - {\cdot}00131b + {\cdot}000002b^2)$$

where t is the temperature in degrees centigrade and b the excess of the barometric height over 760 mm.

The values of ·00108 cosec ϕ and 709 cosec ϕ for different latitudes are as follows:—

Latitude.	·00108 cosec ϕ	709 cosec ϕ
30°	·00216	1418
40°	·00168	1103
50°	·00141	925
60°	·00125	819
70°	·00115	754

Using these numbers we find the following tables giving the values of v corresponding to different values of t, b, and x, in cases where the effect of curvature is neglected.

TABLE I. *Metric Measures.*

FOR OBTAINING THE GRADIENT VELOCITY IN METRES PER SECOND FROM MEASUREMENTS OF THE DISTANCE BETWEEN CONSECUTIVE ISOBARS ON CHARTS TO THE SCALE OF 1/10⁷ AND ON CHARTS OF THE BULLETIN INTERNATIONAL (SCALE 4/10⁸).

FOR LATITUDE 30°.

Pressure.	Temperature.	Velocities in metres per second for * distances between consecutive isobars as follows:—																				
		1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·5	3·0	3·5	4·0	4·5	5·0	6·0	7·0	8·0	9·0 mm.
		2	2·2	2·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4	5	6	7	8	9	10	12	14	16	18 mm
	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
720	−10 C.	144·2	131·1	120·0	111·0	103·0	96·1	90·1	84·8	80·1	75·9	72·1	57·7	48·1	41·2	36·0	32·0	28·8	24·0	20·6	18·0	16·0
	0	149·7	136·1	124·7	115·2	106·9	99·8	93·6	88·1	83·2	78·8	74·8	59·9	49·9	42·8	37·4	33·3	29·9	24·9	21·4	18·7	16·6
	10	155·2	141·1	129·3	119·4	110·9	103·5	97·0	91·3	86·2	81·7	77·6	62·1	51·7	44·3	38·8	34·5	31·0	25·9	22·2	19·4	17·2
	20	160·7	145·2	133·9	123·6	114·8	107·1	100·4	94·5	89·3	84·6	80·3	64·3	53·6	45·9	40·2	35·7	32·1	26·8	23·0	20·1	17·9
	30	166·2	151·1	138·5	127·8	118·7	110·8	103·9	97·2	92·3	87·5	83·1	66·5	55·4	47·5	41·5	36·9	33·2	27·7	23·7	20·8	18·5
760	−10 C.	136·5	124·1	113·7	105·0	97·5	91·0	85·3	80·3	75·8	71·8	68·2	54·6	45·5	39·0	34·1	30·3	27·3	22·7	19·9	17·1	15·2
	0	141·8	129·8	118·2	109·1	101·3	94·5	88·6	83·4	78·8	74·6	70·9	56·7	47·3	40·5	35·4	31·5	28·4	23·6	20·3	17·7	15·8
	10	147·1	133·7	122·6	113·2	105·1	98·1	91·9	86·5	81·7	77·4	73·5	58·8	49·0	42·0	36·8	32·7	29·4	24·5	21·0	18·4	16·3
	20	152·4	138·5	127·0	117·2	108·9	101·6	95·1	89·6	84·7	80·2	76·2	61·0	50·8	43·5	38·1	33·9	30·5	25·4	21·8	19·0	16·9
	30	157·7	143·4	131·4	121·3	112·6	105·1	99·9	92·8	87·6	83·0	78·8	63·1	52·6	45·1	39·4	35·0	31·5	26·3	22·5	19·7	17·5
800	−10 C.	129·7	117·9	108·1	99·8	92·6	86·5	81·1	76·1	72·1	68·3	64·8	51·9	43·2	37·1	32·4	28·8	25·9	21·6	18·5	16·2	14·4
	0	134·6	122·4	112·2	103·5	96·1	89·7	84·1	79·2	74·8	70·8	67·3	53·8	44·9	38·5	33·6	29·9	26·9	22·4	19·2	16·8	15·0
	10	139·5	126·8	116·2	107·3	99·6	93·0	87·2	82·1	77·5	73·4	69·7	55·8	46·5	39·9	34·9	31·0	27·9	23·2	19·9	17·4	15·5
	20	144·4	131·3	120·3	111·1	103·1	96·3	90·2	84·9	80·2	76·0	72·2	57·8	48·1	41·3	36·1	32·1	28·9	24·1	20·6	18·0	16·0
	30	149·3	135·7	124·4	114·8	106·6	99·5	94·3	87·8	82·9	78·6	74·6	59·7	49·8	42·7	37·3	33·2	29·9	24·9	21·3	18·7	16·6

* NOTE.—The distances in the first row are for isobars drawn for steps of 1 mm. on charts to the scale of 1/10⁷, (10 kilometres on the natural scale).
The distances in the second row are for isobars drawn for steps of 5 mm. on charts to the scale of 4/10⁸.

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† *See* note on page 42 with reference to the relation of the curvature of the isobar and the curvature of the path.

For Latitude 40°.

Pressure.	Temperature.	Velocities in metres per second for * distances between consecutive isobars as follows:—																				
		1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·5	3·0	3·5	4·0	4·5	5·0	6·0	7·0	8·0	9·0 mm
		2	2·2	2·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4	5	6	7	8	9	10	12	14	16	18 mm.
	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
720	−10 C.	112·2	102·0	93·5	86·3	80·1	74·8	70·1	66·0	62·3	59·1	56·1	44·9	37·4	32·1	28·0	24·9	22·4	18·7	16·0	14·0	12·5
	0	116·4	105·8	97·0	89·5	83·1	77·6	72·7	68·5	64·7	61·3	58·2	46·6	38·8	33·3	29·1	25·9	23·3	19·4	16·6	14·5	12·9
	10	120·7	109·8	100·6	92·8	86·2	80·5	75·4	71·0	67·1	63·5	60·3	48·3	40·2	34·5	30·2	26·8	24·1	20·1	17·2	15·1	13·4
	20	124·9	113·5	104·1	96·1	89·2	83·3	78·1	73·5	69·4	65·7	62·4	50·0	41·6	35·7	31·2	27·8	25·0	20·8	17·8	15·6	13·9
	30	129·2	117·4	107·7	99·4	92·3	86·1	80·7	76·0	71·8	68·0	64·6	51·7	43·1	36·9	32·3	28·7	25·9	21·5	18·5	16·1	14·4
760	−10 C.	106·3	96·6	88·6	81·8	75·9	70·9	66·4	62·5	59·1	55·9	53·1	42·5	35·4	30·4	26·6	23·6	21·3	17·7	15·2	13·3	11·8
	0	110·3	100·3	91·9	84·8	78·8	73·5	68·9	65·8	61·3	58·1	55·1	44·1	36·8	31·5	27·6	24·5	22·1	18·4	15·8	13·8	12·3
	10	114·3	103·9	95·2	87·9	81·6	76·2	71·4	67·2	63·5	60·2	57·1	45·7	38·1	32·7	28·6	25·4	22·9	19·0	16·3	14·3	12·7
	20	118·3	107·5	98·6	91·0	84·5	78·9	73·9	69·6	65·7	62·3	59·1	47·3	39·4	33·8	29·6	26·3	23·7	19·7	16·9	14·8	13·1
	30	122·4	111·3	102·0	94·2	87·4	81·6	76·5	72·0	68·0	64·4	61·2	49·0	40·8	35·0	30·6	27·2	24·5	20·4	17·5	15·3	13·6
800	−10 C.	101·0	91·8	84·2	77·7	72·3	67·3	63·1	59·4	56·1	53·2	50·5	40·5	33·7	28·9	25·2	22·4	20·2	16·8	14·4	12·6	11·2
	0	104·8	95·3	87·3	80·6	74·9	69·9	65·5	61·6	58·2	55·2	52·4	41·9	34·9	29·9	26·2	23·3	21·0	17·5	15·0	13·6	11·8
	10	108·6	98·7	90·5	83·5	77·6	72·4	67·9	63·9	60·3	57·2	54·3	43·4	36·2	31·0	27·1	24·1	21·7	18·1	15·5	13·6	12·1
	20	112·4	102·2	93·7	86·5	80·3	74·9	70·2	66·1	62·4	59·2	56·2	45·0	37·5	32·1	28·1	25·0	22·5	18·7	16·1	14·0	12·5
	30	116·2	105·6	96·8	89·4	83·0	77·5	72·6	68·4	64·6	61·2	58·1	46·5	38·7	33·2	29·0	25·8	23·2	19·4	16·6	14·5	12·9

For Latitude 50°.

Pressure.	Temperature.	Velocities in metres per second for * distances between consecutive isobars as follows:—																				
		1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·5	3·0	3·5	4·0	4·5	5·0	6·0	7·0	8·0	9·0 mm.
		2	2·2	2·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4	5	6	7	8	9	10	12	14	16	18 mm.
	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
720	−10 C.	94·1	85·5	78·4	72·4	67·2	62·7	58·8	55·4	52·3	49·5	47·0	37·6	31·4	26·9	23·5	20·9	18·8	15·7	13·4	11·8	10·5
	0	97·6	88·7	81·3	75·1	69·7	65·1	61·0	57·4	54·2	51·4	48·8	39·0	32·5	27·9	24·4	21·7	19·5	16·3	13·9	12·2	10·8
	10	101·1	91·9	84·2	77·8	72·2	67·4	63·2	59·5	56·2	53·2	50·5	40·4	33·7	28·9	25·3	22·5	20·2	16·8	14·4	12·6	11·2
	20	104·7	95·2	87·2	80·5	74·8	69·8	65·4	61·6	58·2	55·1	52·3	41·9	34·9	29·9	26·2	23·3	20·9	17·4	15·0	13·1	11·6
	30	108·2	98·4	90·2	83·2	77·3	72·1	67·6	63·6	60·1	56·9	54·1	43·3	36·1	30·9	27·0	24·0	21·6	18·0	15·5	13·5	12·0
760	−10 C.	89·1	81·0	74·2	68·5	63·6	59·4	55·7	52·4	49·5	46·9	44·5	35·6	29·7	25·5	22·3	19·8	17·8	14·8	12·7	11·1	9·9
	0	92·5	84·1	77·1	71·2	66·1	61·7	57·8	54·4	51·4	48·7	46·2	37·0	30·8	26·4	24·1	20·6	18·5	15·4	13·2	11·6	10·3
	10	95·9	87·2	79·9	73·8	68·5	63·9	59·9	56·4	53·3	50·5	47·9	38·3	32·0	27·4	24·0	21·3	19·2	16·0	13·7	12·0	10·7
	20	99·3	90·3	82·7	76·4	70·9	66·2	62·1	58·4	55·2	52·3	49·6	39·7	33·1	28·4	24·8	22·1	19·9	16·5	14·2	12·4	11·0
	30	102·7	93·4	85·6	79·0	73·4	68·5	64·2	60·4	57·1	54·1	51·3	41·1	34·2	29·5	25·7	22·8	20·5	17·1	14·7	12·8	11·4
800	−10 C.	84·7	77·0	70·6	65·2	60·5	56·5	52·9	49·8	47·1	44·7	42·3	33·9	28·2	24·2	21·2	18·8	16·9	14·1	12·1	10·6	9·4
	0	87·9	79·9	73·2	67·6	62·8	58·6	54·9	51·7	48·8	46·3	43·9	35·2	29·3	25·1	22·0	19·5	17·6	14·6	12·6	11·0	9·8
	10	91·1	82·8	75·9	70·1	65·1	60·7	56·9	53·6	50·6	47·9	45·5	36·4	30·4	26·0	22·8	20·2	18·2	15·2	13·0	11·4	10·1
	20	94·3	85·7	78·6	72·5	67·4	62·9	58·9	55·5	52·4	49·6	47·1	37·7	31·4	26·9	23·6	21·0	18·9	15·7	13·5	11·8	10·5
	30	97·5	88·6	81·2	75·0	69·6	65·0	60·9	57·4	54·2	51·3	48·7	39·0	32·5	27·9	24·4	21·7	19·5	16·2	13·9	12·2	10·8

For Latitude 60°.

Pressure.	Temperature.	Velocities in metres per second for * distances between consecutive isobars as follows:—																				
		1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·5	3·0	3·5	4·0	4·5	5·0	6·0	7·0	8·0	9·0 mm.
		2	2·2	3·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4	5	6	7	8	9	10	12	14	16	18 mm.
	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
720	−10 C.	83·3	75·7	69·4	64·1	59·5	55·5	52·1	49·0	46·3	43·8	41·6	33·3	27·8	23·8	20·8	18·5	16·7	13·9	11·9	10·4	9·3
	0	86·4	78·5	72·0	66·5	61·7	57·6	54·0	50·8	48·0	45·5	43·2	34·6	28·8	24·7	21·6	19·2	17·3	14·4	12·3	10·8	9·6
	10	89·6	81·5	74·7	68·9	64·0	59·7	56·0	52·7	49·8	47·2	44·8	35·8	29·9	27·6	22·4	19·9	17·9	14·9	12·8	11·2	10·0
	20	92·7	84·3	77·2	71·3	66·2	61·8	57·9	54·5	51·4	48·8	46·3	37·1	30·9	26·5	23·2	20·6	18·5	15·4	13·2	11·6	10·3
	30	95·9	87·2	79·9	73·8	68·5	63·9	59·9	56·4	53·2	50·5	47·9	38·4	32·0	27·4	24·0	21·3	19·2	16·0	13·7	12·0	10·7
760	−10 C.	78·9	71·7	65·7	60·7	56·4	52·6	49·3	46·4	43·8	41·5	39·4	31·6	26·3	22·5	19·7	17·5	15·8	13·1	11·3	9·9	8·8
	0	81·9	74·5	68·2	63·0	58·5	54·6	51·2	48·2	45·5	43·1	40·9	32·8	27·3	23·4	20·5	18·2	16·4	13·6	11·7	10·2	9·1
	10	84·9	77·2	70·7	65·3	60·6	56·6	53·1	49·9	47·2	44·7	42·4	34·0	28·3	24·3	21·2	18·9	17·0	14·1	12·1	10·6	9·4
	20	87·9	79·9	73·2	67·6	62·8	58·6	54·9	51·7	48·8	46·3	43·9	35·2	29·3	25·1	22·0	19·5	17·6	14·6	12·6	11·0	9·8
	30	90·9	82·6	75·7	69·9	64·9	60·6	56·8	53·5	50·5	47·8	45·4	36·4	30·3	26·0	22·7	20·2	18·2	15·1	13·0	11·4	10·1
800	−10 C.	75·0	68·2	62·5	57·7	53·6	50·0	46·9	44·1	41·7	39·5	37·5	30·0	25·0	21·4	18·7	16·7	15·0	12·5	10·7	9·4	8·3
	0	77·8	70·7	64·8	59·8	55·6	51·9	48·6	45·8	43·2	41·0	38·9	31·1	25·9	22·2	19·4	17·3	15·6	13·0	11·1	9·7	8·6
	10	80·7	73·4	67·2	62·1	57·6	53·8	50·4	47·5	44·8	42·5	40·3	32·3	26·9	23·1	20·2	17·9	16·1	13·4	11·5	10·1	9·0
	20	83·5	75·9	69·6	64·2	59·6	55·7	52·2	49·1	46·4	44·0	41·7	33·4	27·8	23·9	20·9	18·6	16·7	13·9	11·9	10·4	9·3
	30	86·4	78·5	72·0	66·5	61·7	57·6	54·0	50·8	48·0	45·5	43·2	34·6	28·8	24·7	21·6	19·2	17·3	14·4	12·3	10·8	9·6

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* NOTE.—The distances in the first row are for isobars drawn for steps of 1 mm. on charts to the scale of $1/10^7$, (10 kilometres on the natural scale).

The distances in the second row are for isobars drawn for steps of 5 mm. on charts to the scale of $4/10^8$.

For Latitude 70°.

Pressure.	Temperature.	Velocities in metres per second for * distances between consecutive isobars as follows :—																				
		1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·5	3·0	3·5	4·0	4·5	5·0	6·0	7·0	8·0	9·0 mm.
		2	2·2	2·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4	5	6	7	8	9	10	12	14	16	18 mm.
	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
720	−10 C.	76·6	69·6	63·8	58·9	54·7	51·1	47·9	45·1	42·6	40·3	38·3	30·6	25·5	21·9	19·1	17·0	15·3	12·8	10·9	9·6	8·5
	0	79·5	72·3	66·2	61·2	56·8	53·0	49·7	46·8	44·2	41·8	39·7	31·8	26·5	22·7	19·9	17·7	15·9	13·2	11·4	9·9	8·8
	10	82·4	74·9	68·7	63·4	58·9	54·9	51·5	48·5	45·8	43·4	41·2	33·0	27·5	23·5	20·6	18·3	16·5	13·7	11·8	10·3	9·2
	20	85·3	77·5	71·1	65·6	60·9	56·9	54·6	50·2	47·4	44·9	42·6	34·1	28·4	24·4	21·3	19·0	17·1	14·2	12·2	10·7	9·5
	30	88·2	80·2	73·5	67·8	63·0	58·8	55·1	51·9	49·0	46·4	44·1	35·3	29·4	25·2	22·0	19·6	17·6	14·7	12·6	11·0	9·8
760	−10 C.	72·7	66·1	60·6	55·9	51·9	48·5	45·4	42·8	40·4	38·2	36·3	29·1	24·2	20·8	18·2	16·2	14·5	12·1	10·4	9·1	8·1
	0	75·4	68·5	62·8	58·0	53·9	50·3	47·1	44·4	41·9	39·7	37·7	30·2	25·1	21·5	18·8	16·8	15·1	12·6	10·8	9·4	8·4
	10	78·1	71·0	65·1	60·1	55·8	52·1	48·8	45·9	43·4	41·1	39·0	31·2	26·0	22·3	19·5	17·4	15·6	13·0	11·2	9·8	8·7
	20	80·9	73·5	67·4	62·2	57·8	53·9	50·6	47·6	44·9	42·6	40·4	32·4	27·0	23·1	20·2	18·0	16·2	13·5	11·6	10·1	9·0
	30	83·6	76·0	69·7	64·3	59·7	55·7	52·2	49·2	46·2	44·0	41·8	33·4	27·9	23·9	20·9	18·6	16·7	13·9	11·9	10·4	9·3
800	−10 C.	69·0	62·7	57·5	53·1	49·3	46·0	43·1	40·6	38·3	36·3	34·5	27·6	23·0	19·7	17·2	15·3	13·8	11·5	9·9	8·6	7·7
	0	71·6	65·1	59·7	55·1	51·1	47·7	44·7	42·1	39·8	37·7	35·8	28·6	23·9	20·5	17·9	15·9	14·3	11·9	10·2	8·9	8·0
	10	74·2	67·5	61·8	57·1	53·0	49·5	46·4	43·6	41·2	39·1	37·1	29·7	24·7	21·2	18·5	16·5	14·8	12·4	10·6	9·3	8·2
	20	76·8	69·8	64·0	59·1	54·9	51·2	48·0	45·2	42·7	40·4	38·4	30·7	25·6	21·9	19·2	17·1	15·4	12·8	11·0	9·6	8·5
	30	79·4	72·2	66·2	61·1	56·7	52·9	49·6	46·7	44·1	41·8	39·7	31·8	26·5	22·7	19·8	17·6	15·9	13·2	11·3	9·9	8·8

* **Note.**—The distances in the first row are for isobars drawn for steps of 1 mm. on charts to the scale of $1/10^7$, (10 kilometres on the natural scale).
The distances in the second row are for isobars drawn for steps of 5 mm. on charts to the scale of $4/10^8$.

The Scale of the Bulletin International is 4 mm. to 100 km., and 5 mm. isobars only are drawn, so that the tables are immediately applicable to these charts as indicated.

The tables are given to fractions of a metre per second in order that the result for any particular case may be calculated to the nearest metre per second. This involves measuring the distance between millimetre isobars to the nearest kilometre for ordinarily large velocities. The exceptionally high values might occur with very curved isobars near the centre of cyclones: the values would be then so far reduced for curvature that an error of 5 metres per second in the straight isobar velocity might be reduced to about 1 m.p.s. for the final velocity corrected for curvature.

For the new working charts of the Meteorological Office the scale is 1 cm. to 100 kilometres or 1 to 10^7. On these charts the isobars are drawn for each tenth of an inch, and we get for the coefficients in the velocity formula

$$v\,(1 \pm v \cot \rho \operatorname{cosec} \phi \times {\cdot}00108) = \frac{180{\cdot}1}{x_1}\,\frac{T}{T_0}\,\frac{B_0}{B} \operatorname{cosec} \phi,$$

where x_1 is the distance in millimetres between $\frac{1}{10}$-in. isobars and v is still expressed in metres per second. Taking for standard pressure and temperature 30 in. and 32° F. we find

$$v\,(1 \pm v \cot \rho \operatorname{cosec} \phi \times {\cdot}00108) = \frac{179{\cdot}6}{x_1} \operatorname{cosec} \phi\,(1 + {\cdot}002\,t - {\cdot}00333b + {\cdot}000011b^2)$$

where t is the excess of temperature F. above 32° F. and b the number of $\frac{1}{10}$ in. by which the pressure exceeds 30 ins. The values of 179·6 cosec ϕ are as follows :—

ϕ	30°	40°	50°	60°	70°
179·6 cosec ϕ	359	279	235	207	191

The tables giving the values of v, when the term involving v^2 is neglected, are given below.

TABLE II.

For obtaining the Gradient Velocity in Metres per Second from Measurements of the Distance between Consecutive Isobars on the New Charts, to Scale of $1/10^7$.

For Latitude 30°.

Pressure.	Temperature.	For Distances between $\frac{1}{10}$-inch isobars :—																			
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20. mm.
		·04	·08	·12	·16	·20	·24	·28	·32	·35	·39	·43	·47	·51	·55	·59	·63	·67	·71	·75	·79 ins.
in.	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
28	12 F.	368	184	123	92	73·6	61·3	52·5	46·0	40·8	36·8	33·4	30·6	28·3	26·2	24·5	23·0	21·6	20·4	19·4	18·4
	32	384	192	128	96	76·8	64·0	54·8	48·0	42·6	38·4	34·9	32·0	29·5	27·4	25·6	24·0	22·6	21·3	20·2	19·2
	52	400	200	133	100	80·0	66·6	57·1	50·0	44·4	40·0	36·3	33·3	30·7	28·5	26·7	25·0	23·5	22·2	21·1	20 0
	72	416	208	139	104	83·2	69·3	59·4	52·0	46·2	41·6	37·8	34·6	32·0	29·7	27·7	26·0	24·5	23·1	21·9	20·8
29	12 F.	356	178	119	89	71·2	59·3	50·8	44·5	39·5	35·6	32·3	29·6	17·3	25·4	23·7	22·2	20·9	19·7	18·7	17·8
	32	371	185	124	93	74·2	61·8	53·0	46·3	41·2	37·1	33·7	30·9	28·5	26·5	24·7	23·1	21·8	20·6	19·9	18·5
	52	386	193	129	96	77·2	64·3	55·1	48·2	42·8	38·6	35·1	32·1	29·7	27·5	25·7	24·1	22·7	21·4	20·3	19·3
	72	401	200	134	100	80·2	66·8	57·2	50·1	44·5	40·1	36·4	33·4	30·8	28·6	26·7	25·0	23·6	22·2	21·1	20·0
30	12 F.	344	172	115	86	68·8	57·3	49·1	43·0	38·2	34·4	31·2	28·6	26·4	24·5	22·9	21·5	20·2	19·1	18·1	17·2
	32	359	179	120	90	71·8	59·8	51·2	44·8	39·8	35·9	32·6	29·9	27·6	25·6	23·9	22·4	21·1	19·9	18·9	17·9
	52	374	187	125	93	74·8	62·3	53·4	46·7	41·5	37·4	34·0	31·1	28·8	26·7	24·9	23·3	22·0	20·7	20·0	18·7
	72	388	194	129	97	77·6	64·6	55·4	48·5	43·1	38·8	35·2	32·3	29·8	27·7	25·9	24·2	22·8	21·5	20·4	19·4
31	12 F.	333	166	111	83	66·6	55·5	47·5	41·6	37·0	33·3	30·2	27·7	25·6	23·7	22·2	20·8	19·6	18·5	17·5	16·6
	32	347	173	116	87	69·4	57·8	49·5	43·3	38·5	34·7	31·5	28·9	26·7	24·7	23·1	21·6	20·4	19·2	18·3	17·3
	52	361	180	120	90	72·2	60·1	51·5	45·1	40·1	36·1	32·8	30·1	27·8	25·7	24·1	22·5	21·2	20·0	19·0	18·0
	72	375	187	125	94	75·0	62·5	53·5	46·8	41·6	37·5	34·1	31·2	28·8	26·7	25·0	23·4	22·1	20·8	20·0	18·7

For Latitude 40°.

Pressure.	Temperature.	For Distance between $\frac{1}{10}$-inch isobars :—																			
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20. mm.
		·04	·08	·12	·16	·20	·24	·28	·32	·35	·39	·43	·47	·51	·55	·59	·63	·67	·71	·75	·79 ins.
in.	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
28	12 F.	287	143	96	72	57·4	47·8	41·0	35·8	31·8	28·7	26·1	23·9	22·1	20·5	19·1	17·9	16·9	15·9	15·1	14·3
	32	299	149	100	75	59·8	49·8	42·7	37·3	33·2	29·9	27·1	24·9	25·3	21·3	19·9	18·6	17·6	16·6	15·7	14·9
	52	311	155	104	78	62·2	51·8	44·4	38·8	34·5	31·1	28·2	25·9	23·9	22·2	20·7	19·4	18·3	17·2	16·4	15·5
	72	323	161	108	81	64·6	53·8	46·1	40·3	35·8	32·3	29·3	26·9	24·8	23·0	21·5	20·1	19·0	17·9	17·0	16·1
29	12 F.	277	138	92	69	55·4	46·1	39·5	34·6	30·7	27·7	25·1	23·1	21·3	19·7	18·5	17·3	16·3	15·3	14·6	13·8
	32	289	144	96	72	57·8	48·1	41·2	36·1	32·1	28·9	26·2	24·1	22·2	20·6	19·3	18·0	17·0	16·0	15·2	14·4
	52	301	150	100	75	60·2	50·1	43·0	37·6	32·3	30·1	27·3	25·1	23·1	21·5	20·1	18·8	17·7	16·1	15·8	15·0
	72	313	156	104	78	62·6	52·1	44·7	39·1	34·7	31·3	28·4	26·1	24·1	22·3	20·9	19·5	18·4	17·3	11·2	15·6
30	12 F.	268	134	89	67	53·6	44·6	38·2	33·5	29·7	26·8	24·3	22·3	20·6	19·1	17·9	16·7	15·8	14·8	14·1	13·4
	32	279	140	93	70	55·8	46·5	39·8	34·8	31·0	27·9	25·3	23·2	21·4	19·9	18·6	17·4	16·4	15·5	14·7	14·0
	52	290	145	97	72	58·0	48·3	41·4	36·2	32·2	29·0	26·3	24·1	22·3	20·7	19·3	18·1	17·1	16·1	15·3	14·5
	72	302	151	101	75	60·4	50·3	43·1	37·7	33·5	30·2	27·4	25·1	23·2	21·5	20·1	18·8	17·8	16·7	15·9	15·1
31	12 F.	259	129	86	65	51·8	43·1	37·0	32·3	28·7	25·9	23·5	21·5	20·0	18·5	17·3	16·1	15·2	14·3	13·6	12·9
	32	270	135	90	67	54·0	45·0	38·5	33·7	30·0	27·0	24·5	22·5	20·7	19·2	18·0	16·8	15·9	15·0	14·2	13·5
	52	281	140	94	70	56·2	46·8	40·1	35·1	31·2	28·1	25·5	23·4	21·6	20·0	18·7	17·5	16·5	15·6	14·8	14·0
	72	292	146	97	73	58·4	48·6	41·7	36·5	32·4	29·2	26·5	24·3	22·4	20·8	19·5	18·2	17·2	16·2	15·4	14·6

For Latitude 50°.

Pressure.	Temperature.	For Distances between $\frac{1}{10}$-inch isobars :—																			
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20. mm.
		·04	·08	·12	·16	·20	·24	·28	·32	·35	·39	·43	·47	·51	·55	·59	·63	·67	·71	·75	·79 ins.
in.	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
28	12 F.	242	121	81	60	48·4	40·3	34·6	30·2	26·9	24·2	22·0	20·1	18·6	17·3	16·1	15·1	14·2	13·4	12·7	12·1
	32	252	126	84	63	50·4	42·0	36·0	31·5	28·0	25·2	22·9	21·0	19·3	18·0	16·8	15·7	14·8	14·0	13·3	12·6
	52	262	131	87	65	52·4	43·7	37·4	32·7	29·1	26·2	23·8	21·8	20·1	18·7	17·5	16·3	15·4	14·5	13·8	13·1
	72	272	136	91	68	54·4	45·3	38·9	34·0	30·2	27·2	24·7	22·6	20·9	19·4	18·1	17·0	16·0	15·1	14·3	13·6
29	12 F.	233	116	78	58	46·6	38·8	33·3	29·1	25·9	23·3	21·1	19·4	17·9	16·6	15·5	14·5	13·1	12·9	12·3	11·6
	32	243	121	81	61	48·6	40·5	34·7	30·4	27·0	24·3	22·1	20·2	18·7	17·3	16·2	15·2	14·3	13·5	12·8	12·1
	52	253	126	84	63	50·6	42·2	36·1	31·6	28·1	25·3	23·0	21·1	19·4	18·0	16·9	15·8	14·9	14·0	13·3	12·6
	72	263	131	88	66	52·6	43·8	37·6	32·9	29·2	26·3	23·9	21·9	20·2	18·8	17·5	16·4	15·5	14·6	13·8	13·1
30	12 F.	226	113	75	56	45·2	37·7	32·3	28·2	25·1	22·6	20·5	18·8	17·3	16·1	16·4	14·1	13·3	12·5	11·9	11·3
	32	235	117	78	59	47·0	39·2	33·6	29·4	26·1	23·5	21·3	19·5	18·0	16·8	15·7	14·7	13·8	13·0	12·4	11·7
	52	244	122	81	61	48·8	40·7	34·9	30·5	27·1	24·4	22·1	20·3	18·7	17·4	16·3	15·2	14·4	13·5	12·8	12·2
	72	254	127	85	63	50·8	42·3	36·3	31·7	28·2	25·4	23·1	21·1	19·5	18·1	16·9	15·8	14·9	14·1	13·4	12·7
31	12 F.	219	109	73	55	43·8	36·5	31·3	27·4	24·3	21·9	19·9	18·2	16·8	15·6	14·6	13·7	12·9	12·1	11·5	10·9
	32	228	114	76	57	45·6	38·0	32·6	28·5	25·3	22·8	20·7	19·0	17·5	16·3	15·2	14·2	13·4	12·6	12·0	11·4
	52	237	118	79	59	47·4	39·5	33·9	29·6	26·3	23·7	21·5	19·7	18·2	16·9	15·8	14·8	13·9	13·1	12·5	11·8
	72	247	123	82	62	49·4	41·2	35·3	30·9	27·4	24·7	22·4	20·5	19·0	17·6	16·5	15·4	14·5	13·7	13·0	12·3

FOR LATITUDE 60°.

Pressure.	Temperature.	For Distances between $\frac{1}{10}$-inch isobars:—																			
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20. mm.
		·04	·08	·12	·16	·20	·24	·28	·32	·35	·39	·43	·47	·51	·55	·59	·63	·67	·71	·75	·79 ins.
in.	°	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
28	12 F.	213	106	71	53	42·6	35·5	30·4	26·6	23·6	21·3	19·3	17·7	16·4	15·2	14·2	13·3	12·5	11·8	11·2	10·5
	32	222	111	74	55	44·4	37·0	31·7	27·7	24·6	22·2	20·1	18·5	17·1	15·8	14·8	13·8	13·1	12·3	11·7	11·1
	52	231	115	77	58	46·2	38·5	33·0	28·8	25·6	23·1	21·0	19·2	17·8	16·5	15·4	14·4	13·6	12·8	12·2	11·5
	72	240	120	80	60	48·0	40·0	34·2	30·0	26·6	24·0	21·8	20·0	18·5	17·1	16·0	15·0	14·1	13·3	12·6	12·0
29	12 F.	205	102	68	51	41·0	34·1	29·2	25·6	22·7	20·5	18·6	17·1	15·8	14·6	13·7	12·8	12·1	11·3	10·8	10·2
	32	214	107	71	53	42·8	35·7	30·6	26·7	23·8	21·4	19·4	17·8	16·5	15·3	14·3	13·3	12·6	11·9	11·3	10·7
	52	223	111	74	56	44·6	37·1	31·8	27·8	24·7	22·3	20·2	18·5	17·2	15·9	14·9	13·9	13·1	12·3	11·7	11·1
	72	231	115	77	58	46·2	38·5	33·0	28·8	25·6	23·1	21·0	19·2	17·8	16·5	15·4	14·4	13·6	12·8	12·2	11·5
30	12 F.	199	99	66	50	39·8	33·1	28·4	24·8	22·1	19·9	18·1	16·5	15·3	14·2	13·3	12·4	11·7	11·0	10·5	9·9
	32	207	104	69	52	41·4	34·5	29·5	25·8	23·0	20·7	18·8	17·2	15·9	14·7	13·8	12·9	12·2	11·5	10·9	10·4
	52	216	108	72	54	43·2	36·0	30·8	27·0	24·0	21·6	19·6	18·0	16·6	15·4	14·4	13·5	12·7	12·0	11·4	10·8
	72	224	112	75	56	44·8	37·3	32·0	28·0	24·8	22·4	20·3	18·6	17·2	16·0	14·9	14·0	13·2	12·4	11·8	11·2
31	12 F.	193	96	64	48	38·6	32·1	27·5	24·1	21·4	19·3	17·5	16·1	14·8	13·7	12·9	12·0	11·4	10·7	10·2	9·6
	32	201	100	67	50	40·2	33·5	28·7	25·1	22·3	20·1	18·2	16·7	15·5	14·3	13·4	12·5	11·8	11·1	10·6	10·0
	52	209	104	70	52	41·8	34·8	29·8	26·1	23·2	20·9	19·0	17·4	16·1	14·9	14·0	13·0	12·3	11·6	11·0	10·4
	72	217	108	72	54	43·4	36·1	31·0	27·1	24·1	21·7	19·7	18·1	16·7	15·5	14·5	13·5	12·8	12·0	11·4	10·8

FOR LATITUDE 70°.

Pressure.	Temperature.	For Distances between $\frac{1}{10}$-inch isobars:—																			
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20. mm.
		·04	·08	·12	·16	·20	·24	·28	·32	·35	·39	·43	·47	·51	·55	·59	·63	·67	·71	·75	·79 ins.
in.	°	m/s.	m/s	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
28	12 F.	197	98	66	49	39·4	32·8	28·1	24·6	21·8	19·7	17·9	16·4	15·2	14·0	13·1	12·3	11·6	10·9	10·4	9·8
	32	205	102	68	51	41·0	34·1	29·2	25·6	22·7	20·5	18·6	17·1	15·8	14·6	13·7	12·8	12·1	11·3	10·8	10·2
	52	213	106	71	53	42·6	35·5	30·4	26·6	23·6	21·3	19·3	17·7	16·4	15·2	14·2	13·3	12·5	11·8	11·2	10·6
	72	222	111	74	55	44·4	37·0	31·7	27·7	24·6	22·2	20·1	18·5	17·1	15·8	14·8	13·8	13·1	12·3	11·7	11·1
29	12 F.	190	95	63	47	38·0	31·6	27·1	23·7	21·1	19·0	17·2	15·8	14·6	13·5	12·7	11·8	11·2	10·5	10·0	9·5
	32	198	99	66	49	39·6	33·0	28·2	24·7	22·0	19·8	18·0	16·5	15·2	14·1	13·2	12·3	11·6	11·0	10·4	9·9
	52	206	103	69	51	41·2	34·3	29·4	25·7	22·8	20·6	18·7	17·1	15·8	14·7	13·7	12·8	12·1	11·4	10·8	10·3
	72	214	107	71	53	42·8	35·7	30·6	26·7	23·8	21·4	19·4	17·8	16·5	15·3	14·3	13·3	12·6	11·9	11·3	10·7
30	12 F.	183	91	61	46	36·6	30·5	26·1	22·8	20·3	18·3	16·6	15·2	14·1	13·0	12·2	11·4	10·8	10·1	9·6	9·1
	32	191	95	64	48	38·2	31·8	27·2	23·8	21·2	19·1	17·3	15·9	14·7	13·6	12·7	11·9	11·2	10·6	10·1	9·5
	52	199	99	66	50	39·8	33·1	28·4	24·8	22·1	19·9	18·1	16·5	15·3	14·2	13·3	12·4	11·7	11·0	10·5	9·9
	72	207	103	69	52	41·4	34·5	29·5	25·8	23·0	20·7	18·8	17·2	15·9	14·7	13·8	12·9	12·2	11·5	10·9	10·3
31	12 F.	177	88	59	44	35·4	29·5	25·2	22·1	19·6	17·7	16·1	14·7	13·6	12·6	11·8	11·0	10·4	9·8	9·3	8·8
	32	185	92	62	46	37·0	30·8	26·4	23·1	20·5	18·5	16·8	15·4	14·2	13·2	12·3	11·5	10·9	10·2	9·7	9·2
	52	193	96	64	48	38·6	32·1	27·5	24·1	21·4	19·3	17·5	16·1	14·8	13·7	12·9	12·0	11·4	10·7	10·2	9·6
	72	200	100	67	50	40·0	33·3	28·5	25·0	22·2	20·0	18·1	16·6	15·4	14·2	13·3	12·5	11·8	11·1	10·5	10·0

[NOTE.—The metre per second as the unit of velocity is retained here in spite of the apparent incongruity, because the tables for reduction for curvature have all been calculated for this unit. A change would involve calculation of another set of tables *ab initio*. By adhering to the metre per second throughout we obtain the corrected velocity from the one set of tables and can change it into miles per hour if desired by the auxiliary table printed on. p. 23 for convenience.]

EFFECT OF CURVATURE.

We proceed to construct tables for correcting the velocities, deduced by neglecting the term in v^2, for the curvature that generally exists.

We may write our formula

$$v\ (1 \pm av) = v_0,$$

the $+^{ve}$ sign corresponding to cyclonic (concave towards the lower pressure) and the $-^{ve}$ sign to anticyclonic (convex towards the lower pressure) isobars.

[A simple way of determining the sign is to consider that the effects due to the curvature and the Earth's rotation in the Northern Hemisphere are the same as if forces acted (1) from the concave side of the path at right angles to the direction of motion, (2) at right angles to the path and tending to produce deviation to the right; these forces being in equilibrium with that arising from the pressure gradient.]

The solutions of this equation are

$$v = \frac{1}{2a}\left(-1 + \sqrt{1 + 4\,av_0}\right) \text{ for cyclonic systems,}$$

and

$$v = \frac{1}{2a}\left(1 - \sqrt{1 - 4\,av_0}\right) \text{ for anticyclonic systems,}$$

the sign of the square root being determined by the fact that for very small values of a, $v = v_0$.

The second expression shows that for motion along the isobars, the velocity in anticyclones cannot exceed $\frac{1}{2a}$, where $a = {\cdot}00108 \cot \rho \operatorname{cosec} \phi$.

This maximum velocity is double the velocity for the same gradient with straight isobars: the gradient therefore cannot exceed that corresponding to a velocity $\frac{1}{4a}$. This maximum gradient varies as $\sin^2 \phi$, and is three times as great for lat. 60° as for lat. 30°. For small values of the radius of curvature, the maximum gradient is proportional to that radius.

The following table gives the values of a and $\frac{1}{2a}$ for different values of ρ and ϕ:—

—	Latitude 30°.		Latitude 40°.		Latitude 50°.		Latitude 60°.		Latitude 70°.	
ρ	a	$\frac{1}{2a}$	a	$\overline{2a}$	a	$\frac{1}{2a}$	a	$\frac{1}{2a}$	a	$\frac{1}{2a}$
1° ...	·12375	4·0	·09625	5·2	·08077	6·2	·07161	7·0	·06588	7·6
2° ...	·06185	8·1	·04811	10·4	·04037	12·4	·03579	14·0	·03293	15·2
3° ...	·04121	12·1	·03206	15·6	·02690	18·6	·02385	21·0	·02194	22·8
4° ...	·03089	16·2	·02402	20·8	·02016	24·8	·01788	28·0	·01645	30·4
5° ...	·02469	20·2	·01920	26·0	·01611	31·0	·01429	35·0	·01315	38·0
6° ...	·02055	24·3	·01598	31·3	·01341	37·3	·01189	42·0	·01096	45·7
7° ...	·01759	28·4	·01368	36·5	·01148	43·5	·01018	49·1	·00937	53·4
8° ...	·01537	32·5	·01195	41·8	·01003	49·8	·00889	56·2	·00818	61·1
9° ...	·01364	36·7	·01061	47·1	·00890	56·2	·00789	63·4	·00726	68·9
10° ...	·01225	40·8	·00953	52·5	·00800	62·5	·00709	70·5	·00652	76·7
20° ...	·00593	84·2	·00462	108	·00387	130	·00343	146	·00316	158
40° ...	·00257	194	·00200	250	·00168	298	·00149	336	·00137	365

From these values the following tables have been calculated for finding the effect of curvature on the velocity:—

TABLE III.—*Metric Measures.*

CYCLONIC CIRCULATION.

GRADIENT VELOCITIES CORRECTED FOR DIFFERENT ANGULAR RADII OF CURVATURE OF THE PATHS FOR LATITUDES 30°–70°.

	LATITUDE 30°.											
v.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
5	3·5	4·0	4·25	4·4	4·5	4·56	4·63	4·67	4·70	4·73	4·87	4·90
10	5·8	7·0	7·56	8·02	8·3	8·5	8·6	8·8	8·9	9·01	9·5	9·75
15	7·7	9·5	10·5	11·2	11·6	12·0	12·3	12·6	12·8	13·0	13·9	14·5
20	9·3	11·6	13·0	14·0	14·7	15·2	15·7	16·0	16·4	16·6	18·1	19·1
25	10·7	13·6	15·3	16·5	17·5	18·2	18·8	19·3	19·7	20·1	22·1	23·5
30	12·0	15·4	17·4	18·9	20·1	21·0	21·7	22·3	22·9	23·3	26·0	27·9
35	13·3	17·0	19·4	21·2	22·5	23·6	24·5	25·2	25·9	26·4	29·8	32·2
40	14·4	18·6	21·3	23·3	24·8	26·1	27·1	28·0	28·8	29·4	33·4	36·5
45	15·5	20·1	23·1	25·3	27·0	28·4	29·6	30·6	31·5	32·3	37·0	40·6
50	16·5	21·5	24·7	27·2	29·1	30·7	32·0	33·1	34·2	35·0	40·4	44·7
55	17·4	22·8	26·3	29·0	31·1	32·8	34·3	35·5	36·7	37·6	43·7	48·7
60	18·3	24·1	27·9	30·8	33·0	34·9	36·5	37·9	39·1	40·2	47·0	52·7
65	19·2	25·3	29·4	32·5	34·9	36·9	38·7	40·2	41·5	42·7	50·1	56·6
70	20·1	26·5	30·8	34·1	36·7	38·9	40·8	42·4	43·8	45·1	53·2	60·4
75	20·9	27·7	32·2	35·7	38·5	40·8	42·8	44·5	46·1	47·4	56·3	64·2
80	21·7	28·8	33·5	37·2	40·2	42·6	44·8	46·6	48·3	49·7	59·2	67·9
90	23·2	30·9	36·1	40·2	43·4	46·2	48·5	50·6	52·5	54·1	65·0	75·2
100	24·6	32·9	38·6	43·0	46·5	49·5	52·1	54·4	56·5	58·3	70·6	82·3

	LATITUDE 40°.											
v.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
5	3·7	4·16	4·29	4·52	4·60	4·65	4·70	4·73	4·76	4·78	4·90	4·95
10	6·2	7·4	7·96	8·35	8·6	8·8	8·9	9·0	9·1	9·2	9·6	9·8
15	8·3	10·1	11·0	11·7	12·2	12·5	12·8	13·0	13·2	13·3	14·1	14·6
20	10·1	12·6	13·9	14·8	15·4	15·9	16·3	16·7	17·0	17·2	18·4	19·3
25	11·7	14·7	16·4	17·6	18·5	19·1	19·7	20·2	20·5	20·8	22·7	23·9
30	13·2	16·7	18·7	20·2	21·3	22·2	22·9	23·5	23·9	24·3	26·7	28·4
35	14·6	18·5	20·9	22·7	24·0	25·0	25·9	26·6	27·2	27·7	30·7	32·9
40	15·9	20·2	23·0	25·0	26·5	27·7	28·7	29·6	30·3	30·9	34·5	37·3
45	17·1	21·9	25·0	27·2	28·9	30·3	31·4	32·5	33·3	34·0	38·3	41·6
50	18·2	23·5	26·9	29·3	31·2	32·8	34·1	35·2	36·2	37·0	41·9	45·8
55	19·3	25·0	28·7	31·4	33·5	35·2	36·6	37·9	39·0	39·9	45·5	50·0
60	20·3	26·4	30·4	33·3	35·6	37·5	39·1	40·5	41·6	42·7	49·0	54·2
65	21·3	27·8	32·1	35·2	37·7	39·7	41·5	43·0	44·2	45·4	52·4	58·3
70	22·3	29·1	33·7	37·1	39·7	41·9	43·8	45·4	46·8	49·0	55·7	62·4
75	23·2	30·4	35·2	38·8	41·7	44·0	46·0	47·8	49·3	50·6	59·0	66·3
80	24·1	31·7	36·7	40·5	43·6	46·1	48·2	50·1	51·7	53·1	62·2	70·2
90	25·8	34·1	39·6	43·9	47·2	49·9	52·4	54·6	56·3	58·0	68·4	77·9
100	27·5	36·4	42·4	47·0	50·7	53·6	56·4	58·7	60·8	62·8	74·5	85·4

	LATITUDE 50°.											
v.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
5	3·8	4·3	4·5 4·46	4·6 4·57	4·7 4·66	4·7 4·71	4·7 4·74	4·8 4·77	4·8 4·80	4·8 4·82	4·9 4·93	5·0 4·97
10	6·5	7·6	8·2	8·5	8·8	8·9 8·93	9·1 9·06	9·2 9·16	9·3 9·25	9·3	9·7	9·8
15	8·8	10·5	11·5	12·1	12·5	12·8	13·0	13·2	13·4	13·5	14·3	14·6
20	10·7	13·1	14·4	15·3	16·0	16·4	16·7	17·1	17·3	17·6	18·7	19·4
25	12·5	15·4	17·1	18·3	19·1	19·8	20·3	20·7	21·1	21·4	23·1	24·0
30	14·0	17·6	19·6	21·1	22·2	23·0	23·6	24·2	24·6	25·0	27·3	28·6
35	15·5	19·6	22·0	23·7	25·0	26·0	26·8	27·4	28·0	28·5	31·4	33·2
40	16·9	21·4	24·2	26·2	27·8	28·9	29·8	30·6	31·3	31·9	35·4	37·7
45	18·2	23·2	26·3	28·0	30·3	31·6	32·7	33·7	34·4	35·1	39·3	42·1
50	19·4	24·9	28·3	30·9	32·8	34·2	35·5	36·6	37·5	38·3	43·1	46·4
55	20·6	26·5	30·3	33·0	35·2	36·8	38·2	39·4	40·5	41·4	46·8	50·7
60	21·8	28·1	32·2	35·1	37·4	39·3	40·8	42·2	43·3	44·3	50·5	55·0
65	22·9	29·6	34·0	37·1	39·6	41·7	43·4	44·8	46·1	47·2	54·1	59·2
70	23·9	31·0	35·7	39·1	41·8	44·0	45·9	47·4	48·8	50·0	57·6	61·5
75	24·9	32·4	37·4	41·0	44·0	46·3	48·4	50·0	51·4	52·8	61·0	65·6
80	25·9	33·8	39·0	42·9	46·0	48·5	50·9	52·4	54·0	55·4	64·5	69·6
90	27·8	36·4	42·2	46·5	49·8	52·7	55·6	57·2	59·0	60·6	71·2	76·6
100	29·5	38·9	45·2	49·9	53·6	56·8	59·8	61·8	63·7	65·5	77·2	85·5

	LATITUDE 60°.											
v.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
m/s.	m/s.	m/s	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
5	3·9	4·3	4·5	4·62	4·69	4·74	4·78	4·80	4·82	4·83	4·92	4·97
10	6·8	7·8	8·3	8·7	8·9	9·0	9·1	9·2	9·3	9·4	9·7	9·9
15	9·1	10·8	11·7	12·3	12·7	13·0	13·2	13·4	13·6	13·7	14·3	14·7
20	11·1	13·5	14·8	15·6	16·2	16·7	17·1	17·3	17·5	17·8	18·8	19·4
25	13·0	15·9	17·6	18·7	19·5	20·2	20·7	21·1	21·4	21·7	23·2	24·1
30	14·6	18·2	20·2	21·6	22·7	23·5	24·1	24·6	25·0	25·4	27·4	28·8
35	16·2	20·3	22·7	24·4	25·6	26·6	27·4	28·0	28·6	29·0	31·6	33·3
40	17·7	22·3	25·1	27·0	28·4	29·6	30·6	31·3	32·0	32·5	35·7	37·9
45	19·1	24·2	27·3	29·5	31·1	32·5	33·6	34·5	35·2	35·9	39·6	42·3
50	20·4	26·0	29·4	31·9	33·7	35·3	36·5	37·6	38·4	39·2	43·5	46·7
55	21·6	27·7	31·5	34·2	36·2	38·0	39·3	40·5	41·5	42·3	47·3	51·1
60	22·8	29·3	33·4	36·4	38·7	40·5	42·1	43·3	44·4	45·4	51·0	55·4
65	24·0	30·9	35·3	38·5	41·0	43·0	44·7	46·1	47·3	48·4	54·7	59·7
70	25·1	32·4	37·1	40·6	43·3	45·4	47·3	48·8	50·1	51·3	58·3	63·9
75	26·2	33·9	38·9	42·6	45·5	47·8	49·8	51·4	52·9	54·2	61·9	68·1
80	27·2	35·4	40·7	44·6	47·6	50·1	52·2	54·0	55·6	57·0	65·4	72·2
90	29·2	38·1	44·0	48·3	51·8	54·6	57·0	59·0	60·8	62·4	72·1	80·4
100	31·0	40·7	47·1	51·9	55·7	58·7	61·6	63·8	65·8	67·6	78·8	88·4

	LATITUDE 70.											
v.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
5	3·97	4·37	4·55	4·65	4·71	4·76	4·78	4·81	4·83	4·85	4·92	4·96
10	6·9	7·9	8·44	8·74	8·95	9·11	9·21	9·3	9·36	9·41	9·7	9·84
15	9·3	11·0	11·9	12·4	12·8	13·1	13·3	13·5	13·7	13·8	14·3	14·6
20	11·4	13·8	15·0	15·9	16·5	16·9	17·2	17·5	17·7	17·9	18·9	19·5
25	13·3	16·3	18·0	19·1	19·8	20·5	20·9	21·3	21·6	21·9	23·3	24·2
30	15·1	18·6	20·7	22·0	23·0	23·9	24·4	24·9	25·4	25·7	27·6	28·9
35	16·7	20·7	23·2	24·9	26·1	27·1	27·8	28·4	28·9	29·4	31·8	33·5
40	18·2	22·8	25·6	27·0	29·0	30·2	31·0	31·8	32·4	32·9	35·9	38·0
45	19·6	24·8	27·9	30·1	31·8	33·1	34·1	35·0	35·8	36·4	40·0	42·5
50	21·0	26·6	30·1	32·6	34·4	36·0	37·1	38·1	39·0	39·7	43·9	47·0
55	22·3	28·4	32·2	34·9	37·0	38·8	40·0	41·1	42·1	43·0	47·8	51·4
60	23·5	30·1	34·3	37·2	39·5	41·5	42·8	44·1	45·2	46·1	51·6	55·8
65	24·7	31·8	36·2	39·4	41·9	44·0	45·5	47·0	48·2	49·2	55·3	60·1
70	25·9	33·4	38·1	41·6	44·3	46·5	48·2	49·8	51·1	52·2	59·0	64·4
75	27·0	34·9	40·0	43·7	46·5	48·9	50·8	52·5	54·0	55·1	62·6	68·6
80	28·1	36·4	41·8	45·7	48·7	51·3	53·3	55·1	56·7	58·0	66·2	72·8
90	30·1	39·2	45·2	49·6	53·0	55·9	58·2	60·3	62·1	63·6	73·1	81·0
100	32·1	42·0	48·5	53·3	57·1	60·4	62·9	65·2	67·3	69·0	79·9	89·2

The first column gives the value of v_0, which can be found by measuring the gradient along the normal and using the tables for straight isobars. The remaining columns give the values of the velocity corresponding to these values of v_0 for the different values of ρ.

It will be seen that the lower the latitude the greater is its effect on the velocity for a given value of v_0, and we should therefore expect a very marked effect of latitude on velocity for anticyclonic circulation because the curvature effect is in the same direction as the effect on the value of v_0 for the same gradient. In cyclones the two effects are opposed and the total effect is therefore less marked. Thus for latitudes 50° and 60° the values of v_0, corresponding to a distance of 10 mm. between $\frac{1}{10}$-in. isobars and pressure and temperature 30 in. and 52° F., are 24·4 and 21·6 metres per second.

If the radius of curvature of the path is 10°, (1) cyclonic, (2) anticyclonic, the reduced values of the velocities are (1) 21 and 19 metres per second, (2) 33 and 27 metres per second.

PRACTICAL APPLICATION TO COMPARISONS WITH WINDS GIVEN IN THE BEAUFORT SCALE.

In cases where there is no anemometer to record the wind value, it is customary to report the wind according to the Beaufort scale. An official report on the relation between the Beaufort numbers and the wind velocity, in miles per hour, obtained from the records of the standard Robinson cup anemometer by using the factor 2·2, was published in 1906 (Official No. 180). The velocities deduced from this report have been adopted, and additional numbers have been introduced to allow of application to cases in which the straight isobar gradient velocity is greater than that comprised within the ordinary Beaufort scale. The scale with the additional numbers is shown below. The corresponding velocities and limits of velocity are given in metres per second and miles per hour.

Beaufort Number.	Velocity.		Limits of Velocity.	
	Miles per Hour.	Mètres per Second.	Miles per Hour.	Mètres per Second.
2	5	2·2	3 — 8	1.3 — 3·6
3	10	4·5	8 — 13	3·6 — 5·8
4	15	6·7	13 — 18	5·8 — 8·0
5	21	9·4	18 — 24	8·0 — 10·7
6	27	12·1	24 — 31	10·7 — 13·9
7	35	15·6	31 — 38	13·9 — 17·0
8	42	18·8	38 — 46	17·0 — 20·5
9	50	22·3	46 — 55	20·6 — 24·6
10	59	26·4	55 — 64	24·6 — 28·6
11	68	30·4	64 — 75	28·6 — 33·5
12	87	38·9	75 — 100	33·5 — 44·7
13	112	50·1	100 — 125	44·7 — 55·9
14	137	61·2	125 — 150	55·9 — 67·1

From these numbers and the tables we can construct a scale on transparent material, which shall give directly by application to the new working charts, the Beaufort number corresponding to the theoretical gradient wind for straight isobars for any pressure distribution. Such a scale is given in the frontispiece for latitude 50°, and pressure and temperature 30 in. and 52° F. The variation with pressure and temperature will only affect the number when the velocity is near the limit of velocity to which it corresponds. The scale is so constructed that when the distances between the isobars are those shown, the corresponding Beaufort number would be midway between the two numbers given if the Beaufort scale were continuous. In this way the number occurring between two divisions is the Beaufort number corresponding to the gradient velocity for all pressure distributions with straight isobars, in which the normal distance between the isobars is comprised between those two distances.

The following table gives the distances for constructing the scales for different latitudes ; the distances corresponding to 1·3 will be generally omitted, and winds below 3·6 metres per second regarded as of force 2.

Distances in millimetres between $\frac{1}{10}$-in. isobars on the new working charts corresponding to Beaufort Number velocities for air at 30 in. and 52° F. for various latitudes :—

Velocity.	Latitude.				
	30°.	40°.	50°.	60°.	70°.
Metres per second.	mm.	mm.	mm.	mm.	mm.
1·3	280	220	190	166	153
3·6	104	81	68	60	55
5·8	68	50	42	37	34
8·0	47	36	30	27	25
10·7	35	27	23	20	19
13·9	27	21	18	16	14
17·0	22	17	14	13	12
20·6	18	14	12	10	9·7
24·6	16	12	10	8·8	8·1
28·6	13	10	8·5	7·6	7·0
33·5	11	8·7	7·3	6·5	5·9
44·7	8·4	6·5	5·5	4·8	4·5
55·9	6·7	5·2	4·4	3·9	3·6
67·1	5·6	4·3	3·6	3·2	3·0

For correcting the velocity, deduced by using the scale, on account of the curvature, we take a series of circles of radii 111, 222, &c., kilometres corresponding to angular radii of 1°, 2°, etc. (*see* frontispiece). On the inside of each circle are printed the numbers of the Beaufort scale, and on the other side a series of numbers opposite to them deduced from the tables for curvature correction as indicated below.

To use the circles they are applied to the isobars* and moved until the one most nearly osculating the isobar, near the place under consideration, is found. The straight isobar velocity on the Beaufort scale having been found by means of the scale mentioned above, this number is found among those on the inner side of this circle, and the number opposite to it is the Beaufort number appropriate to the pressure distribution. The terms anticyclonic and cyclonic are used as in the earlier part of the paper.

The tables for reducing for curvature the Beaufort number, determined by measurement of the gradient, have been calculated and are inserted here. A Beaufort number A is regarded as being reduced to a Beaufort number B if the reduced velocity corresponding to the velocity for A falls within the limits of velocity corresponding to B.

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* *See* note on curvature p. 42.

TABLE VI.

TABLE FOR CORRECTING BEAUFORT NUMBERS FOR THE EFFECT DUE TO CURVATURE OF THE PATHS FOR LATITUDES 30°, 50°, 70°.

Cyclonic Circulation.

Beaufort Numbers.	LATITUDE 30°.												LATITUDE 50°.												LATITUDE 70°.											
	Angular radii of Curvature.												Angular radii of Curvature.												Angular radii of Curvature.											
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1, 2, 3	—	—	—	—	—	—	—	—	—	—	—
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2												
3	2	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3												
4	3	3	3	3	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	3	3	4	4	—	—	—	—	—	—	—	—
5	3	4	4	4	4	4	5	5	5	5	5	5	4	4	4	5	5	5	5	5	5	5	5	5	4	4	4	5	—	—	—	—	—	—	—	—
6	4	5	5	5	5	5	5	5	5	6	6	6	4	5	5	5	5	5	6	6	6	6	6	6	4	5	5	5	5	6	6	6	6	6	6	6
7	4	5	6	6	6	6	6	6	6	6	7	7	5	6	6	6	6	6	6	6	7	7	7	7	5	6	6	6	6	6	6	7	7	7	7	7
8	5	6	6	6	7	7	7	7	7	7	8	8	5	6	6	7	7	7	7	7	7	7	8	8	6	6	7	7	7	7	7	7	7	7	8	8
9	5	6	7	7	7	7	8	8	8	8	8	9	6	7	7	7	8	8	8	8	8	8	9	9	6	7	7	8	8	8	8	8	8	8	9	9
10	6	7	7	8	8	8	8	8	9	9	9	10	6	7	8	8	8	9	9	9	9	9	9	10	6	7	8	8	9	9	9	9	9	9	9	10
11	6	7	8	8	8	9	9	9	9	10	10	10	7	8	8	9	9	9	9	9	10	10	10	11	7	8	9	9	9	9	10	10	10	10	10	11
12	7	8	9	9	9	10	10	10	10	11	11	11	7	9	9	10	10	10	11	11	11	11	11	12	8	9	10	10	10	11	11	11	11	11	12	12
13	7	9	10	10	10	11	11	11	12	12	12	12	8	10	11	11	11	11	12	12	12	12	12	13	9	10	11	11	12	12	12	12	12	12	12	13
14	8	9	10	11	11	12	12	12	12	12	13	13	9	10	11	12	12	12	12	12	12	13	13	13 or 14	9	11	12	12	12	12	12	13	13	13	13	14
15	8 or 9	10	11	12	12	13	13	13	13	13	14	14	9 or 10	11	12	12	12	12	13	13	13	13	14	14	10	12	12	13	13	13	13	13	13	14	14	14 or 15

Anticyclonic Circulation.

Beaufort Numbers.	LATITUDE 30°.												LATITUDE 50°.												LATITUDE 70°.											
	Angular radii of Curvature.												Angular radii of Curvature.												Angular radii of Curvature.											
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	20°	40°
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1, 2, 3	—	—	—	—	—	—	—	—	—	—	—
2	—	2 to 3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2												
3	—	—	4	3	3	3	3	3	3	3	3	3	—	4	3	3	3	3	3	3	3	3	3	3												
4	—	—	—	5	5	5	4	4	4	4	4	4	—	5 or 6	5	5	4	4	4	4	4	4	4	4	—	5	5	4	4	4	4	4	4	4	4	4
5	—	—	—	—	7	6	6	6	6	6	5	5	—	—	6 or 7	6	6	6	6	5	5	5	5	5	—	—	6	6	6	5	5	5	5	5	5	5
6	—	—	—	—	—	9	8	7	7	7	6	6	—	—	—	8 or 9	7.	7	7	7	6	6	6	6	—	—	—	7	7	7	7	6	6	6	6	6
7	—	—	—	—	—	—	—	10	9	9	8	7	—	—	—	—	10 or 11	9	8	8	8	8	7	7	—	—	—	—	9	8	8	8	8	8	7	7
8	—	—	—	—	—	—	—	—	—	11	9	8	—	—	—	—	—	11 or 12	10	10	9	9	8	8	—	—	—	—	12	10	9	9	9	9	8	8
9	—	—	—	—	—	—	—	—	—	—	10	9	—	—	—	—	—	—	12	11	11	11	10	9	—	—	—	—	—	12	11	11	10	10	9	9
10	—	—	—	—	—	—	—	—	—	—	11	10	—	—	—	—	—	—	—	12	12	12	11	10	—	—	—	—	—	—	13	12	12	12	11	10
11	—	—	—	—	—	—	—	—	—	—	12	11	—	—	—	—	—	—	—	—	—	13	12	11	—	—	—	—	—	—	—	14	13	12	12	11
12	—	—	—	—	—	—	—	—	—	—	14	12	—	—	—	—	—	—	—	—	—	—	13	12	—	—	—	—	—	—	—	—	—	—	13	12
13	—	—	—	—	—	—	—	—	—	—	—	14	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

MEASURE OF CURVATURE ON MAPS.

It is necessary to consider to what degree of accuracy we can obtain the curvature of the isobars on the Earth's surface from measurements of the isobars drawn on the charts. Isobaric weather maps are usually drawn on a system of conical or polyconic projection, and in the case of conical projection a small circle on the Earth's surface will appear on the map as the developed curve of intersection of two right circular cones, the vertex of the projecting cone being on the axis of the cone to be developed at a normal distance from the surface of the latter equal to the Earth's radius (except when the developable cone is a cutting and not a tangent cone).

If the small circle has an angular radius β with its centre in latitude $\frac{\pi}{2} - \phi$, the equation to the cones may be written

$$x^2 + y^2 = z^2 \tan^2 a$$

$$(x \cos \phi + \overline{z - z_0} \sin \phi)^2 + y^2 = (x \sin \phi - \overline{z - z_0} \cos \phi)^2 \tan^2 \beta.$$

the tangent cone touching in lat. a and $z_0 = \mathrm{R} \operatorname{cosec} a$, where R is the earth's radius.

The polar equation to the developed curve will be obtained from these by putting

$$r_1 = z \sec a, \quad \theta = \sin a \tan^{-1} \frac{y}{x}.$$

The substitution gives

$$r_1^2 \sin^2 a + (r_1 - r_0)^2 \cos^2 a = \sec^2 \beta \, \{r_1 \sin \phi \sin a \cos (\theta \operatorname{cosec} a) - (r_1 - r_0) \cos a \cos \phi\}^2$$

which is a circle only when $\phi = 0$, *i.e.*, for parallels of latitude.

Let us put $r_1 = \mathrm{R}_0 + r \cos \psi$, $\theta = \frac{r \sin \psi}{\mathrm{R}_0}$ as an approximation for cases where β, and consequently θ, is small, where R_0 is the distance from the vertex of the tangent cone to the intersection of the latter with the axis of the projecting cone; and r, ψ, are polar co-ordinates referred to this point and the direction of R_0. We obtain for the equation to the curve

$$r^2 \{1 - \cos^2 \psi \cos^2 (a + \phi)\} = \beta^2 \frac{r_0^2 \sin^2 a \cos^2 a}{\sin^2 (a + \phi)} = \frac{\beta^2 \mathrm{R}^2}{\sin^2 (a + \phi)}.$$

If $(a + \phi) = 90°$ this is the equation to a circle of radius $\mathrm{R}\beta$ and so for all circles of small angular radius whose centres are in the mean latitude, the projected curve is also a circle of radius equal to the curvilinear radius of the small circle. If we write $a + \phi = \frac{\pi}{2} \pm \chi$, χ will be the meridian distance of the centre of the circle from the latitude of the tangent cone. The radius of curvature of the projected curve will be

$$\frac{\mathrm{R}\beta \, (1 - 2 \sin^2 \chi \cos^2 \psi + \sin^4 \chi \cos^2 \psi)^{\frac{3}{2}}}{\cos^3 \chi \, (1 - \sin^2 \chi \cos^2 \psi)^{\frac{3}{2}}}.$$

If we take the maximum value of β to be 10° and the maximum value of χ to be 10° also, we get for the radius of curvature

$$\frac{1{\cdot}05 \times \mathrm{R}\beta \, (1 - {\cdot}06 \cos^2 \psi + {\cdot}001 \cos^2 \psi)^{\frac{3}{2}}}{(1 - {\cdot}03 \cos^2 \psi)^{\frac{3}{2}}},$$

or $\qquad \mathrm{R}\beta \, (1 - {\cdot}05) \, (1 - {\cdot}05 \cos^2 \psi)$ approximately,

which gives a maximum error in estimating the curvature from the map of about 5%, (the value of β being what we want for use in the formulae developed above).

The limit 10° for χ may be fairly taken for a system of polyconic projection for places in the neighbourhood of the mean meridian.

For all great circles $\beta = \frac{\pi}{2}$ and the equation to the developed curve is

$$r_1 \sin \phi \sin a \cos (\theta \operatorname{cosec} a) = (r_1 - r_0) \cos a \cos \phi,$$

which is a straight line only if $a = \frac{\pi}{2}$, *i.e.*, for projection on a tangent cylinder, or for $\phi = \frac{\pi}{2}$ which corresponds to meridians. Great circles on the Earth will therefore not be straight lines on the map, but for middle latitudes the curvature will ~~not be appreciable~~.

EFFECT OF THE TEMPERATURE DISTRIBUTION AT THE SURFACE ON COMPUTATION OF THEORETICAL VELOCITIES IN THE UPPER AIR FROM THE SURFACE DISTRIBUTION OF PRESSURE.

If the surface temperatures and humidities are the same, and the variation of temperature and humidity upwards are also the same over the area considered, the theoretical gradient velocity will not change appreciably as we ascend, and the velocity at any level ought to be the same as at any other level and equal to the velocity deduced from the surface pressure distribution.

If the vertical temperature gradient changes, however, from point to point, or if there be a surface temperature gradient, the velocity will change both in magnitude and direction as we move upwards. We have means of estimating approximately the horizontal temperature gradient, and we may correct the theoretical velocity for this.

If p is the surface pressure, the pressure at height h is approximately given by

$$p_h = pe^{-\frac{h}{kT_1}}$$

where T_1 is the mean temperature of the air column.

If the pressure at a height h above the intersection of the isobar $p + dp$ with the isotherm $T - dT$ is the same as p_h, we get

$$(p + dp)\, e^{-\frac{h}{k(T_1 - dT)}} = pe^{-\frac{h}{kT_1}}$$

$$\text{or } \frac{dp}{p} = \frac{h}{k}\frac{dT}{T_1^2}.$$

Now let $y\,dp$ be the normal distance between the isobars p and $p + dp$, and $x\,dT$ that between the isotherms T and $T - dT$, and let ψ be the angle between the direction of the gradient wind and a corresponding direction with reference to the isotherms, *i.e.*, with the lower temperature on the left for the Northern Hemisphere. Then the angle between the isobars above and below is given by*

$$\tan\phi = \frac{y\,dp}{x\,dT \operatorname{cosec}\psi + y\,dp\cot\psi}$$

$$= \frac{y\sin\psi}{\frac{x\,kT_1^2}{h\,p} + y\cos\psi}.$$

But, now, if T is the surface temperature $p = g\rho\,k\,T$

$$\therefore \tan\phi = \frac{y\sin\psi}{\frac{x}{g\rho\,h}\cdot\frac{T_1^2}{T} + y\cos\psi}.$$

If h is 1,000 metres, the difference between T and T_1 may be neglected in comparison with either, and if the isobars are drawn for each $\frac{1}{10}$ in. and the isotherms for each degree Fahrenheit the expression for $\tan\phi$ becomes

$$\frac{y\sin\psi}{13\,x + y\cos\psi}.$$

The difference of temperature between two points on the isobars p, $p + dp$ where they are cut at right angles is $\frac{y\,dp\cos\psi}{x}$, $= dt$ say.

The distance between the upper isobars through these points is $y\,dp\cos\phi$.

The pressure difference is

$$(p + dp)\, e^{-\frac{h}{k(T_1 + dt)}} - pe^{-\frac{h}{kT_1}}$$

$$= dp\, e^{-kT_1}\left(1 + \frac{phy\cos\psi}{x}\cdot\frac{1}{kT_1^2}\right)$$

and the velocity above will bear to that corresponding to the isothermal state, the ratio

$$\left(1 + \frac{phy\cos\psi}{x}\frac{1}{kT_1^2}\right)\sec\phi.$$

$$= \left(\frac{x\,T_1^2}{g\rho\,h\,T} + y\cos\psi\right)\sec\phi\,\frac{g\rho\,h\,T}{x\,T_1^2} = \frac{\sin\psi}{\sin(\psi - \phi)}$$

---

* *See* fig. p. 29.

For $h = 1{,}000$ metres, and isobars and isotherms as above, this ratio becomes

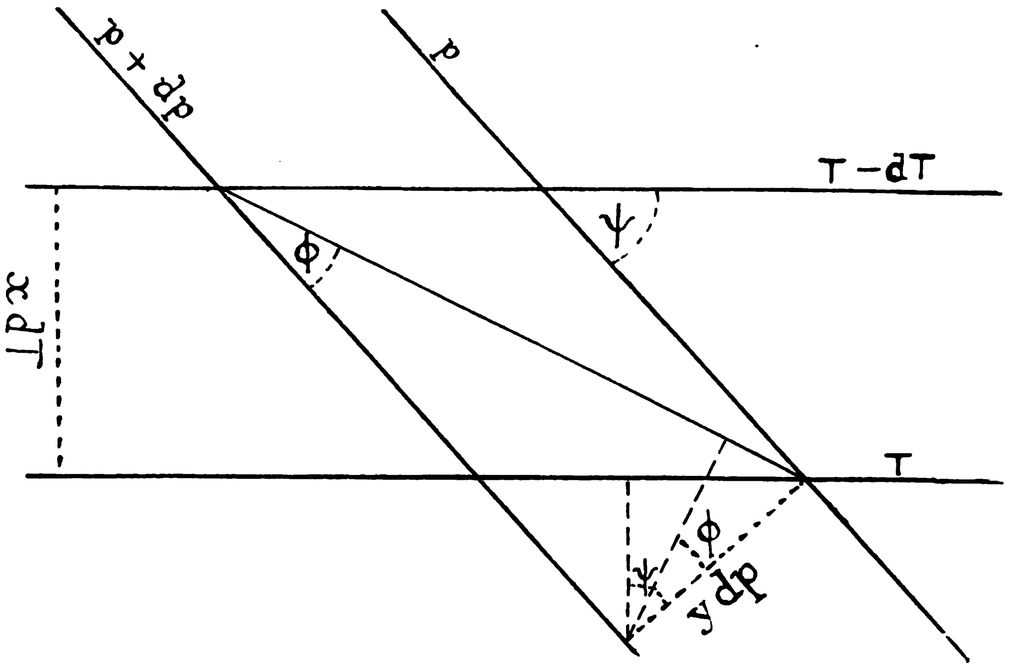
$$\frac{13\,x + y\cos\psi}{13\,x\cos\phi} = \frac{\sqrt{y^2 + 26\,xy\cos\psi + 169\,x^2}}{13\,x}.$$

If $\psi = 0$ this is $1 + \frac{y}{13\,x}$

$\psi = \pi$ this is $1 - \frac{y}{13\,x}$.

If we take as an example $\psi = 0, y = 1\text{ cm} = 2\,x$ for working charts, the gradient velocity is increased from 21 m.p.s at the surface to about 24 m.p.s at 1,000 metres.

If $\psi = \frac{\pi}{2}$ the change in the velocity would be small, but the change in direction would be about 9°, the deflection being in all cases such as to rotate the gradient wind towards the corresponding direction for isotherms.



II.

Comparison of Calculated Velocities with those Observed in the Free Air.

In order to obtain a comparison between the theoretical wind according to the formula taken and the wind observed in the free atmosphere, the observations taken at Berlin during 1905 at 1,000 metres altitude were tabulated. The pressure and temperature at the time of observation were also recorded and the distances between the isobars, drawn for every $\frac{1}{10}$ in., were measured on the English working chart for the hour nearest to that of the observation, generally 8 a.m. The approximate curvature of the* isobars near Berlin was also measured and in this way the velocity to the nearest metre per second was calculated. The velocities were taken from the table for latitude 50° and about 7 per cent. was deducted to allow for the difference in latitude and for the fact that the scale of the working charts was then 0·75 m. to 100 nautical miles, which is nearly 3 per cent. larger than the scale for which the tables were made. The results of these calculations are shown in the accompanying tables :—

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* *See* note on p. 42.

TABLE VII.

COMPARISON BETWEEN GRADIENT WIND AND OBSERVED WINDS ON THE SURFACE, AT 1,000 METRES, AND AT 2,000 METRES ALTITUDE FOR EACH DAY OF THE YEAR, 1905 (BERLIN AND LINDENBERG).

JANUARY.

Date—January.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind. At Surface.	Direction and Velocity of Observed Wind. At 1,000 metres.	Direction and Velocity of Observed Wind. At 2,000 metres.	Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	11	...	NE 11	N 3	NE 17	NE 21	0	— 6
2	4	2 A.	WSW ? 5	Z	NE 3	...	+ 10 ?	— ?
3	21	...	W by S 21	SW 2	W 7	W 10	1	14
4	16	...	NW 16	WSW 4	NW 14	...	0	2
5	25	10 C.	W by N 21	SW 6	W by N 19	...	0	2
6	15	...	WNW ? 15	WSW 4	WNW 20	...	0	— 5
7	28	5 C.	NW 21	W 12	WNW 25	...	— 2	— 4
8	15	10 A.	W 17	SW 2	W 14	NW 15	0	2
9	22	...	W by S 22	WSW 4	W by N 20	...	2	2
10	27	10 C.	NW by W 23	W 10	W 20	...	— 3	3
11	31	...	WNW 31	W 8	W by N 25	...	— 1	6
12	26	...	W by N 26	SW 6	WNW 26	WNW 28	1	0
13	27	...	NW 27	WNW 14	NNW 27	NNW 22	2	0
14	11	...	NNE 11	N 4	NE 9	ENE 17	2	2
15	6	5 A.	E 7	NE 4	E 8	E 18	0	— 1
16	10	...	SSE 10	E 5	ESE 15	SE 14	— 4	— 5
17	18	10 C.	S by E 16	ESE 4	SSE 22	ESE 23	— 1	— 6
18	12	...	SSE 12	E 3	SE 10	SSE 14	— 2	— 2
19	5	...	SE by S 5	ESE 3	SSE 8	SE 6	1	— 3
20	7	...	SE by S 7	E 3	ESE 5	ESE 7	— 3	2
21	8	6 A.	SE by S 9	E 3	ESE 13	SE 18	— 3	— 4
22	8	3 A.	S 12	ESE 3	SSE 9	SSE 7	— 2	3
23	8	...	SW by S 8	SSE 2	SSW 8	...	— 1	0
24	8	...	WSW 8	S 2	SSW 6	...	— 4	2
25	14	10 C.	W by S 13	Z	WSW 7	...	— 1	6
26	15	4 C.	NNW 12	W 6	NW 15	...	— 2	— 3
27	15	6 A.	NNW 21	WNW 3	NNE 18	N 25	4	3
28	7	7 C.	W by N 6	W 3	NW 7	...	3	— 1
29	28	. .	NW 28	WNW 15	NW 28	...	0	0
30	22	...	NW by W 22	W 8	about. WNW 22	WNW 19	— 1	0
31	28	8 C.	W by N 23	W 9	WSW 25	...	— 3	— 2
1.	2.	3.	4.	5.	6.	7.	8.	9.

FEBRUARY.

Date—February.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind. At Surface.	Direction and Velocity of Observed Wind. At 1,000 metres.	Direction and Velocity of Observed Wind. At 2,000 metres.	Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	28	...	W by N 28	W 10	W 29	...	— 1	— 1
2	25	10 C.	W by N 21	W 11	W 26	W 27	— 1	— 5
3	18	...	NW 18	W 8	WNW 20	...	— 2	— 2
4	16	...	WNW 16	WSW 3	WNW 18	...	0	— 2
5	12	10 A.	NW 13	W 5	NNW 10	N 10	2	3
6	11	...	W by N 11	WSW 4	W 12	W 10	— 1	— 1
7	15	...	W by N 15	WSW 4	W 15	...	— 1	0
8	10	5 A.	NNW 12	W 2	NW 7	...	— 2	— 5
9	5	5 A.	W by S 6	WSW 1 (WSW	about. NNW 1 5 at 500 m.)	...	...	5
10	14	...	W by S 14	SW 2	W 11	WSW 15	1	3
11	20	8 C.	WNW 17	W 6	W 16	...	— 2	1
12	16	9 C.	NNW 14	WNW 7	NNW 11	...	0	3
13	7	...	N by W 7	NW 4	N 8	...	1	— 1
14	12	...	WSW 12	SSW 1	W 6	...	2	6
15	5	3 C.	NNW 4	WNW 3	N 6	...	2	— 2
16	7	...	W by S 7	WSW 2	WNW 7	...	3	0
17	17	...	WSW 17	SW 4	WSW 13	WSW 8	0	4
18	10	...	W by N 10	W 2	WNW 7 at 500 m.	...	1	3
19	14	10 C.	W by S 13	SW 4	WSW 17	...	— 1	— 4
20	9	5 C.	W 8	SW 2	WSW 5	...	— 2	3
21	4	8 A.	ENE 4	NE 1	E 3	...	2	1
22	13	10 C.	ESE 12	E 5	E 13	...	— 2	— 1
23	14	...	SE 14	ESE 6	ESE 10	ESE 12	— 2	4
24	9	...	SE 9	E 5	ESE 15	ESE 15	— 2	— 6
25	13	3 C.	W by S 10	SW 2	WSW 12	...	— 1	— 2
26	5	9 A.	S by W 5	S 1	SSE 5	...	— 3	0
27	8	6 C.	S 7	SSE 3	S 8 at 500 m.	...	0	— 1
28	12	8 C.	SW 11	S 3	SW 10	SW 12	0	1
1.	2.	3.	4.	5.	6.	7.	8.	9.

TABLE VII.—*continued.*

MARCH.								
Date—March.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface	At 1,000 metres.	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	8	8 C.	SW 7	S 4	SW 6	...	0	1
2	12	10 C.	E 11	NE 2	E 12	...	0	−1
3	11	2 C.	NE by E 8	NE 3	ENE 7	...	1	1
4	8	9 C.	ENE 7	ENE 3	E 3	...	2	4
5	2	1 A.	ESE 3	ENE 2	E 1	...	−2	2
6	4	...	WSW 4	NE 1	W 1	...	2	3
7	...	Central	...	W 2	NW 2	...	...	...
8	6	? 1 C.	SSW 4	SE 2	SSE 3	...	−4	1
9	13	...	WSW 13	SSW 3	WSW 16	...	0	−3
10	13	10 C.	W by S 12	WSW 3	WSW 10	WSW 12	−1	2
11	19	...	WSW 19	SSW 4	WSW 15	...	0	4
12	15	...	SW by W 15	S 4	SW 12	...	−1	3
13	13	...	SW by W 13	SSW 4	SW 9	SW 13	−1	4
14	14	...	S by W 14	SSE 3	S 15	S 8	−1	−1
15	6	...	SSW 6	S 1	SSW 4	...	0	2
16	7	7 C.	SSW 6	Z	Z	WSW 4	4	6
17	4	...	S 4	SSE 2	SSE 1	...	−2	3
18	4	3 C.	SSW 4	Z	WNW 2	...	8	2
19	5	3 C.	S 4	E 3	SE 6	...	−4	−2
					at 500 m.			
20	2	? 3 C.	NNW 2	Z	NW 1	...	−2	1
21	9	9 A.	ESE 10	E 4	ESE 7	...	0	3
22	10	8 A.	SE 11	SE 5	SE 8	...	0	3
23	9	...	SSE 9	SSE 5	SE 10	SE 10	−2	−1
24	10	...	SE by E 10	E 5	E 9	...	−3	1
25	6	...	E by S 6	E 4	E 6	...	−1	0
26	? 4	? 1–2 C.	SE? 4	E 3	E 4	...	−4	0
					at 500 m.			
27	? 4	2 A.	WSW 5	SE 1	WNW 3	...	4	2
28	Centre of cyclone	...	Z.	W 3	WNW 4	...	...	...
29	9	...	SW by W 9	SSE 3	WSW 6	...	1	3
30	9	10 C.	WSW 8	Z	W 7	...	2	1
31	7	...	NW by W 7	NNW 4	WNW 6	...	−1	1
1.	2.	3.	4.	5.	6	7.	8.	9.

APRIL.								
Date—April.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface.	At 1,000 metres	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	12	8 C.	NW by W 11	W 5	WNW 15	...	−1	−4
2	9	10 A.	WSW 10	SSE 3	SSW 11	...	−4	−1
3	13	2 C.	NNW 9	NW 4	NW 11	...	−2	−2
4	7	6 A.	W 8	WSW 2	W 5	NW 6	0	3
5	13	8 C.	W 12	WSW 4	W 12	...	0	0
6	19	7 C.	NW by W 16	W 7	WNW 25	...	−1	−9
7	13	9 A.	W by N 15	WSW 5	W 10	...	−1	5
8	14	8 A.	NNW 17	NW 5	NW 9	...	−2	8
9	17	...	WNW 17	W 6	W 11	...	−2	6
10	4	...	SW 4	SW 4	WSW 7	...	2	−3
11	12	2 C.	S by E 9	SE 4	SSW 6	...	3	3
12	7	...	NW 7	W 6	NW 8	...	0	−1
13	6	2 A.	NW 10	W 3	W 5	...	...	5
					at 300 m.			
14	5	...	SE 5	E 4	E 5	Calm	−4	0
15	9	...	SE 9	E 6	ESE 9	...	−2	0
16	11	...	ESE 11	E 6	ESE 12	...	0	−1
17	9	...	E 9	NE 6	ENE 7	ENE 7	−2	2
18	16	...	E by N 16	NNE 5	ENE 9	E 6	−1	7
19	9	...	NE by N 9	N 6	NNE 9	...	1	0
20	9	6 C.	WNW 8	Z	Z	...	...	...
					Mid-day			
21	6	3 C.	ESE 5	NE 4	N 3	...	...	2
22	12	6 C.	NW by N 10	NW 7	WNW 10	...	−3	0
23	12	...	WNW 12	WSW 7	W 9	W 12	−2	3
24	9	6 C.	SW by W 8	SW 5	SW 6	...	−1	2
25	13	...	W by N 13	SW 6	W 10	...	−1	3
26	11	...	WSW 11	SSW 3	SW 6	...	−2	5
27	...	...	...	N 1	Z	WNW 1	...	...
28	10	7 C.	SW 9	SSW 5	SW 9	WSW 9	0	0
29	12	5 C.	SW by W 10	S 6	SW 7	...	0	3
30	6	? 5 C.	SSW 5	SW 4	SW 8	...	−2	−3
1.	2.	3.	4.	5.	6.	7.	8.	9.

TABLE VII.—*continued.*

MAY.

Date—May.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind. At Surface.	At 1,000 metres.	At 2,000 metres.	Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	11	10 C.	SW by W 10	WSW 6	WSW 10	WSW 11	1	0
2	11	3 C.	SW 9	S 6	S by E 7	to calm.	− 5	2
3	10	...	WSW 10	SW 4	WSW 7	...	0	3
4	5	3 A.	WSW 6	Z	WSW 2	WSW 2	0	4
5	14	...	E 14	NNE 5	E 15	E 17	0	− 1
6	12	6 C.	SE by E 11	E 7	SE 11	SE 15	1	0
7	11	6 C.	S by E 10	SE 6	S 12	S 11	1	− 2
8	8	4 C.	WNW 7	WSW 5	WSW 7	...	− 4	0
9	11	4 A.	N by W 16	NW 7	NNW 9	NNW 9	− 1	7
10	9	...	NW 9	W 6	W 8	...	− 4	1
11	9	...	WNW 9	WSW 6	WNW 8	WNW 13	0	1
12	8	7 C.	NW 7	W 3	WNW 7	...	− 2	0
13	6	...	N by E 6	NNW 5	NNW 4	...	− 3	2
14	6	...	NNE 6	NNE 3	NE 2	...	2	4
15	7	6 A.	ENE 8	NE 6	ENE 9	ENE 9	0	− 1
16	10	...	E 10	NE 5	E 10	E 6	0	0
17	14	...	E 14	ENE 5	E 6	...	0	8
18	6	8 A.	E by S 6	NNE 5	E 6	...	− 1	0
19	...	...	...	Z	E 4	...	...	...
20	7	3 C.	N 6	WNW 3	NW 4	...	− 4	2
21	9	4 C.	NW by N 8	W 6	WNW 9	...	− 3	1
22	8	...	W 8	SW 7	W 8	W 10	0	0
23	6	3 A.	NNW 7	N 1	N 4	N 4	2	3
24	3	1 A.	NNW 5	N 3	N 2	...	2	3
25	...	...	...	Z to 1	W 2	...	...	...
26	...	...	...	Z to 1	Z	...	...	...
27	...	...	...	SSE 5	S 3	...	...	...
28	4	...	WSW 4	SE 1	S small.	...	− 6	...
29	...	...	...	Z	Z	ENE	..	...
30	3	...	SSW 3	S 3	Z to 1	SSE	− 4	2
31	6	...	SW 6	SSE	SSW 4	...	− 2	2
1.	2.	3.	4.	5.	6.	7.	8.	9.

JUNE.

Date—June.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind. At Surface.	At 1,000 metres.	At 2,000 metres.	Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	7	...	W by N 7	WNW 5	W 6	W 7	− 1	1
2	3	3 A.	WNW ? 3	W 3	WNW 2	WSW 4	0	1
3	7	...	WSW 7	SW 2	SW 6	...	− 2	1
4	4	3 C.	S 4	S 3	S 4	S 2	0	0
5	...	...	...	SW 3	SW 5	SW 5	...	...
6	...	...	...	NW 3	W 2	...	...	...
7	...	...	...	NNE 5	NE 3	ENE 3	...	...
8	8	2 C.	NNE 6	NE 2	SW 1	Z	− 14	5
9	10	6 A.	E 12	ENE 5	E 7	Z	0	5
10	9	10 A.	ESE 10	ENE 5	E 6	...	− 2	4
11	7	...	E by S 7	ENE 5	ESE 8	...	1	− 1
12	...	...	...	ENE 2	ENE 2–3	...	...	...
13	7	6 A.	E by S 8	ENE 4	E 6	...	− 1	2
14	5	...	SE ? 5	WNW 1	Z	...	...	5
15	6	10 C.	SE 6	E 4	SE 2	SE 4	0	4
16	5	...	SE 5	E 5	SE 5	...	0	0
17	5	...	NE 5	N 5	NNE 9	NNE 8	− 2	− 4
18	Central	Central	...	WNW 3	WSW 5	SW 5	...	...
19	8	5 A.	NW 9	W 5	NW 7	WNW 4	0	2
20	Central	Central	...	ESE 1	NE 2	...	...	...
21	Central	Central	...	S 2	Z	...	...	...
22	10	...	NW 10	W 6	W 20	W 12	− 4	10
23	12	6 A.	NNW 15	NW 6	N 12	...	2	3
24	3	...	NE 3	NNE 1	NE 2	ESE 5	0	1
25	6	8 C.	SE 6	ESE 5	SE 9	SE 13	0	− 3
26	7	7 C.	SE 6	ESE 6	SE 12	SE 14	0	− 6
27	7	1 C.	SW 5	S 6	SSW 8	SSW 12	− 2	− 3
28	10	...	WSW 10	SSW 4	WSW 7	WSW 9	0	3
29	3	...	SW 3	Z	SW 4	SW 5	0	− 1
30	5	4 C.	SE 5	SE 1	ESE 4	Z	− 2	1
1.	2.	3.	4.	5.	6.	7.	8.	9.

TABLE VII.—*continued.*

July.									August.								
Date—July.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).	Date—August.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, −....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface.	At 1,000 metres.	At 2,000 metres.							At Surface.	At 1,000 metres.	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.		m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per. sec.
1	3	2 C.	SSE 3	SE 2	SE 4	S 2	— 2	1	1	...	...	...	ESE 6	SSE 5	...	...	...
2	...	...	...	ESE 1	ESE 4	SE 2	...	...	2	8	4 C.	NNW 7	W 3	W 6	...	— 6	1
3	5	4 A.	NW by W 6	W 1	WNW 6	...	— 1	0	3	...	...	...	SE 6	Z	...	...	...
4	...	...	...	NW 1	W 5	WSW 7	...	...	4	7	7 C.	S by W 6	SSE 3	SSW 5	...	1	1
5	9	2 C.	SSE 7	ESE 1	W 2	W 7	10	5	5	8	2 C.	NW 6	W 5	WNW 4	...	— 2	2
6	9	...	NW 9	NNW 5	NW by W 8	...	— 1	1	6	8	7 A.	NW by N 9	NNW 7	NNW 8	Z	1	1
7	7	...	NW 7	WNW 7	NW 9	WNW 16	0	— 2	7	9	5 C.	N by E 8	NNW 7	NNW 10	Z	— 3	— 2
8	8	4 A.	WNW 10	WNW 6	WNW 9	NW 6	0	1	8	...	...	...	SSE 1	WSW 3	WSW 6	...	...
9	...	...	...	W 5	W 7	...	...	...	9	8	...	SW 8	SSW 1	WSW 6	SW 4	2	2
10	4	...	WNW 4	W 2	NW 6	WNW 3	2	— 2	10	10	4 C.	WSW 9	SW 6	WSW 10	SW 10	0	— 1
11	9	10 A.	NW by N 10	W 5	WNW 9	WNW 13	— 1	1	11	7	...	WNW 7	W 5	WNW 9	WSW 13	0	— 2
12	7	3 A.	NNW 9	W 7	NW 13	NW 17	— 2	— 4	12	17	...	WNW 17	W 8	WNW 12	WNW 10	0	5
13	7	7 A.	NW by W 8	WNW 4	WNW 9	WNW 12	— 1	— 1	13	14	...	W by N 14	WNW 7	WNW 7	WNW 5	0	7
14	16	4 C.	NNW 13	W 6	WNW 9	WNW 11	— 4	4	14	2–5	5 A.	W by S 3	W 2	W 3	W 3	1	0
15	8	7 A.	WNW 9	WSW 3	WSW 3	WNW 4	— 4	6	15	6	...	SSW 6	S 4	S 6	S 4	— 2	0
16	6	...	W by S 6	WSW 4	W 8	...	1	— 2	16	...	...	?	SSW 3	WSW 2	WSW 5	...	...
17	7	...	NW by N 7	NW 6	NW 7	NW 9	— 1	0	17	5	5 A.	NE 6	NNE 4	N 4	...	— 4	2
18	6	...	W 6	SW 1	WSW 8	...	— 2	— 2	18	4	2 A.	SE by E 5	ESE 5	ESE 5	Z	— 1	0
19	15	10 C.	NW 14	W 8	? WNW 10	...	— 2	4	19	14	4 C.	SW 11	S 5	SW 9	SW 16	0	2
20	17	5 C.	NW 14	W 10	W 13	...	— 4	1	20	12	...	W by S 12	SW 7	WSW 9	WSW 9	— 1	3
21	14	6 C.	NW 13	W 8	WNW 12	WNW 12	— 2	1	21	7	...	NW by N 7	WNW 4	WNW 5	...	— 3	2
22	11	10 C.	NW 10	W 6	WNW 14	NW 16	— 2	— 4	22	6	6 A.	S by W 7	ESE 5	S 4	Z	— 1	3
23	6	...	W 6	Z	W 8	...	0	— 2	23	8	3 C.	SW by S 7	SE 5	S 6	SW 11	— 3	1
24	6	7 C.	WNW 6	W 5	NW 8	...	2	— 2	24	11	...	W by S 11	SW 6	WSW 8	WSW 10	— 1	3
25	9	10 A.	NW by N 10	WNW 7	NW 7	NW 6	— 1	3	25	8	3 A.	WSW 11	W 3	SSW 3	...	— 4	8
26	7	...	NW 7	WNW 6	NW 8	NW 14	0	— 1	26	10	5 C.	SE by S 9	E 7	SE 7	SSW 1	— 1	2
27	6	6 A.	WSW by W 7	SSW 3	SW 7	W 8	— 1	0	27	3	2 C.	SW 3	SW 1	SW 6	...	0	— 3
28	...	...	?	Z	SW 2	...	...	...	28	12	...	SW 12	SW 6	SW 8	SW 12	0	3
29	5	...	NE by N 5	NNE 4	NNE 7	...	— 1	— 2	29	12	4 C.	SW 10	SW 7	SW 15	WSW 8	0	— 5
30	13	6 C.	SW by W 11	SSE 6	SW 10	SW 15	1	1	30	12	10 C.	W 11	SSW 6	W 20	...	0	— 9
31	11	...	W 11	W 7	W 8	W 9	0	3	31	20	7 C.	NW by N 17	WNW 8	about. NW 20	NNW 20	— 1	— 3
1.	2.	3.	4.	5.	6.	7.	8.	9.	1.	2.	3.	4.	5.	6.	7.	8.	9.

TABLE VII.—*continued.*

SEPTEMBER.

Date—September.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, –....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface.	At 1,000 metres.	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	18	...	NW by W 18	W 6	W 16	W by N 17	— 3	2
2	18	10 A.	W 22	SW 8	W 18	W 12	0	4
3	17	...	NW by W 17	W 8	W by N 16	WNW 22	— 2	1
4	15	...	NW by N 15	NW 9	NNW 22	NNW 20	1	— 7
5	8	6 A.	W by S 9	SSW 3	W 11	W 12	1	— 2
6	9	...	SSW 9	S ? 4	S ? 4	...	?— 4	5
7	13	7 C.	WSW 11	SSW 4	evening WSW 9	SW 11	0	2
8	12	...	W by S 12	WNW 8	W by N 10	WSW 21	2	2
9	11	6 A.	W by S 13	WSW 4	W 6	...	1	7
10	19	...	SW by W 19	SSW 8	WSW 14	WSW 22	1	5
11	10	...	W 10	W 1	W 7	...	0	3
12	...	...	...	Z	Z	...	...	...
13	...	...	...	NNE 1	NE 2	...	...	...
14	...	...	...	NE 5	E 7	...	...	...
15	7	4 A.	N 8	N 3	NNE 12	N 8	2	— 4
16	4	2 A.	NW 5	W 5	W 7	W 13	— 4	— 2
17	13	...	NW 13	WNW 8	NW 13	...	0	0
18	...	...	...	SE 1	Calm	...	...	...
19	13	...	SSE 13	ESE 8	ESE 17	ESE 11	— 4	— 4
20	6	...	SSE 6	E 6	SE 8	SE 14	— 2	— 2
21	7	3 C.	E 6	NE 5	E 8	E 9	0	— 2
22	7	4 A.	E by N 8	NE 4	ENE 8	ENE 12	— 1	0
23	5	...	E by S 5	E 4	ESE 5	...	1	0
24	11	10 C.	SE 10	E 7	SE 14	...	0	— 4
25	7	4 C.	SSE 5	E 6	SE 9	S 5	— 2	— 4
26	6	3 C.	WSW 5	SSW 4	WSW 7	...	0	— 2
27	5	4 C.	SSE 5	ENE 4	at 500 m. ESE 9	ESE 8	— 4	— 4
28	...	...	...	SW 3	SW 7	SW 9	...	...
29	2	5 C.	SSE 2	E 3	Z	...	...	...
30	12	7 C.	WSW 11	WSW 5	W 13	W 15	— 1	— 2
1.	2.	3.	4.	5.	6.	7.	8.	9.

OCTOBER.

Date—October.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, –....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface.	At 1,000 metres.	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	23	8 C.	WNW 19	SW 15	W by N 27	W by N 20	— 1	— 8
2	13	...	W by S 13	WSW 6	WSW ? 10	...	— 1	3
3	11	3 C.	W 9	WSW 6	W 7	WNW 9	0	2
4	10	6 A.	W by S 12	WSW 5	WNW 10	W 11	3	2
5	20	8 C.	WSW 17	SSW 7	SW 21	WSW 19	— 2	— 4
6	14	5 C.	W by N 12	SW 8	WSW 16	...	— 3	— 4
7	23	5 C.	NW 18	W 9	WNW 15	WNW 20	— 2	3
8	13	5 C.	NNW 11	WNW 6	NW 12	...	— 2	— 1
9	12	7 C.	W 11	WSW 4	W 8	W 12	0	3
10	8	5 C.	NE 7	NNE 6	ENE 8	ENE 10	2	— 1
11	13	...	NE by E 13	ENE 7	ENE 19	ENE 20	1	— 6
12	3	...	NNW 3	NE 2	E 2	E 2	10	1
13	21	7 C.	W by S 17	SW 10	W 25	W 25	1	— 8
14	19	10 C.	NW by W 17	W 9	WNW 12	WNW 17	— 1	5
15	33	5 C.	W by N 24	SW 20	WSW 35 approx.	...	— 3	—11 ?
16	16	10 C.	WNW 14	WSW 13	W 15	...	— 2	— 1
17	15	10 C.	WNW 13	SW 7	WNW 10	WNW 10	0	3
18	12	9 C.	W by S 11	SW 6	WSW 9	...	— 1	2
19	6	...	W by S 6	SW 2	WSW 6	...	— 1	0
20	4	...	NW 4	WNW 2	NW 3	Z	0	1
21	12	5 C.	SW 10	SSE 3	SSW 10	...	— 2	0
22	6	4 C.	SSW 5	SE 5	S 4	...	— 2	1
23	8	5 C.	SW 7	SW 2	SW 4	WSW 4	0	3
24	...	...	...	SW 3	Calm	...	...	...
25	6	...	W 6	SW 2	WSW 4	...	— 2	2
26	10	...	NW 10	WNW 4	NNW 8	NNW 8	2	2
27	15	...	W by S 15	SW 5	W by S 12	...	0	3
28	15	7 C.	W by N 13	SW 7	W 21	...	— 1	— 8?
29	11	10 A.	W by S 12	about SW 2	W 9	...	1	3
30	15	...	SW by W 15	SW 4	WSW 9	WSW 9	1	6
31	21	10 C.	SW 19	S 6	SW 15 to over 20	...	0	4
1.	2.	3.	4.	5.	6.	7.	8.	9.

TABLE VII.—*continued.*

NOVEMBER.								
Date—November.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.-Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, -....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface.	At 1,000 metres.	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	10	...	SW 10	S 4	WSW 6	...	2	4
2	9	7 C.	SE by S 8	E 7	ESE 12	ESE 12	— 3	— 4
3	14	4 C.	SW by W 11	SSW 7	WSW 9	SW 12	1	3
4	9	5 A.	WSW 10	SSW 3	W by S 9	W by S 8	1	1
5	16	9 C.	SSE 14	E by S 10	ESE 9	SE 10	— 4	5
6	10	3 C.	SW 8	SSE 6	WSW 10	SW 20	2	— 2
7	2	3 A.	W 2	Z	Z	Z	...	...
8	9	6 A.	E 10	E by N 6	ESE 8	...	2	2
9	9	4 C.	NE 8	N by E 8	NE 10	NE 8	0	— 2
10	11	3 C.	N by E 9	N 8	NNE 7	...	— 1	2
11	6	2 C.	NW 4	WSW 3	W 3 at 500 m.	Z	— 4	1
12	8	10 C.	SE 7	NE 3	E 4	E 2	— 4	3
13	13	7 C.	SSE 11	E 10	ESE 15	SE 5	— 4	— 4
14	14	...	E by N 14	ENE 8	E by N 13	E 8	0	1
15	18	5 C.	N by W 14	NW 7	NNW 12	NNW 9	— 1	2
16	9	4 C.	NW by W 8	W 6	WNW 8	NW 11	— 1	0
17	11	...	NW 11	W 6	WNW 11	WNW 8	— 2	0
18	10	...	WNW 10	W 2	WNW 9	W 8	0	1
19	11	6 C.	SE 10	E 8	ESE 12	SSE 10	— 2	— 2
20	11	5 C.	NNW 10 irregular.	W 8	W 15	WNW 25	— 6	— 5
21	4	...	W 4	S 3	W 5	W 5	0	— 1
22	7	...	WSW 6	Z	SW 3	WSW 7	— 2	3
23	15	...	WSW 15	SW 5	SW 8	SW 11	— 2	7
24	13	7 C.	W by N 12	SW 8	WNW 20	NW 18	1	— 8
25	13	...	W by N 13	WSW 8	WNW 12	...	1	1
26	15	...	SW by W 15	S by E 7	SW by S 15	SW by S 11	— 2	0
27	33	8 C.	SW 26	S 12	SW 32	...	0	— 6
28	20	...	W by S 20	SW 9	WSW 15	WSW 18	— 1	5
29	4	...	SW by W 4	SSE 3	WSW 4	...	1	0
30	3	...	E 3	E 3	NW 8 at 500 m.	E 5 at 2.40 p.m.	...	...
1	2.	3.	4.	5.	6.	7.	8.	9.

DECEMBER.								
Date—December.	Gradient Wind-velocity uncorrected for curvature.	Angular radius of curvature of Isobars. A.—Anticyclonic. C.—Cyclonic.	Direction of Isobars and Velocity of Gradient Wind corrected for curvature.	Direction and Velocity of Observed Wind.			Deviation of Observed Wind at 1,000 metres (column 6) from direction of Isobars (column 4). (+....veering, -....backing).	Differences between Gradient Wind-velocity (column 4) at 1,000 metres and Observed Wind-velocity (column 6).
				At Surface.	At 1,000 metres.	At 2,000 metres.		
	m. per sec.		m. per sec.	m. per sec.	m. per sec.	m. per sec.	"points."	m. per sec.
1	7	...	SE 7	E 7	? SE 6	...	0	1
2	2	...	? S 2	ENE 4	Z	Z	...	2
3	3	...	? S 3	E by N 4	SE 7	...	? — 4	— 4
4	7	...	SE 7	E 6	SSE 8	...	2	— 1
5	...	...	...	Z	Z	...	...	...
6	11	10 C.	SW 10	S by W 4	WSW 7	WSW 6	2	3
7	14	...	SW by W 14	SSW 5	WSW 12	W 6	1	2
8	13	...	W by S 13	SW 6	W 15	W 19	1	— 2
9	7	...	W 7	W 4	WNW 13	WNW 12	2	— 6
10	13	...	NW 13	W 7	NW 10	NW 12	0	3
11	6	5 A.	NW 7	NW 2	NNE 6	...	6	1
12	14	...	WNW 14	W by S 4	WNW 8	WNW 7	0	6
13	25	...	NW 25	W by N 11	NW 30	...	0	— 5
14	15	...	NW by N 15	WNW 6	NW 14	NNW 12	— 1	1
15	14	...	NW by W 14	W 8	WNW 12	NW 15	— 1	2
16	16	...	NW 16	W 10	WNW 20	...	— 2	— 4
17	15	...	NNW 15	WNW 8	N 12	N 12	2	3
18	9	...	N 9	NW 2	N 5	...	0	4
19	8	...	S by W 9	ESE 3	S 6	...	— 1	3
20	14	...	W by S 14	SW 6	W 10	...	1	4
21	18	...	W 18	SW 6	W 19 at 500 m.	...	0	— 1
22	13	...	WNW 13	W by S 7	WNW 20	NNW 25	0	— 7
23	8	...	NW by N 8	WNW 6	NNW 12	N 10	1	— 4
24	6	...	NW by N 6	W 2	NNW 7	...	1	— 1
25	7	10 A.	W by S 7	SSW 3	SW 3	...	— 3	4
26	12	...	NW 12	W 8	NW 10	...	0	2
27	6	...	WNW 6	W 3	WNW 3	...	0	3
28	...	...	...	Z	NNW 5	...	...	...
29	9	4 C.	S by E 8	ESE 7	S by E 5	...	0	3
30	16	4 C.	NNE 13	N 8	NNE 12	NNE 19	0	1
31	13	...	N 13	NW 4	NNE 7	NNE 11	2	6
1.	2.	3.	4.	5.	6.	7.	8.	9.

An examination of the tables reveals the fact of a remarkable general agreement between the theoretical and observed velocities. In the case of isobars showing anticyclonic curvature, the theoretical velocity is generally slightly greater than the observed. It will be noted, too, that the majority of the cases, where the observed wind veers from the gradient wind, belong to anticyclonic circulation indicating a tendency for the air to flow towards the region of high pressure: it is to be noted, however, that on the average, even for anticyclones, the tendency is for the wind at 1,000 metres altitude to blow slightly across the isobars from the high pressure to the low. The tendency to back from the gradient direction is greater in summer than in winter, a difference due partly to the fact of less steadiness in the warm season, but partly perhaps to the difference in temperature distribution. The majority of the winds are westerly, and in winter the corresponding direction for the isotherms is northerly. The isobars above would therefore tend to give a gradient wind direction veering slightly from that below, and if the wind on the average tended to keep the same inclination, to the isobars at the level at which it was measured, it would on the average have less inclination to those at the surface.

In summer, on the contrary, the prevailing winds are still westerly, while the corresponding direction for the isotherms is S. to S.W.

This would produce a backing in the isobars above and a corresponding increase in the average deviation of the observed wind from the gradient. [In June the prevailing winds were easterly.] Closer examination of the temperature distribution may reveal an average identity of direction between the theoretical and observed winds.

With straight isobars the general agreement in magnitude is better than with cyclones or anticyclones, but the tendency is for the calculated velocity to be too high. There are a few exceptions as on 22nd June, but in that case the velocity at 1,000 metres was greater than that on either side, above or below, and may be regarded as exceptional.

The table of averages gives a summary of the results for each month in the year and for the two seasons, summer and winter.

TABLE VIII.

COMPARISON BETWEEN GRADIENT WIND AND OBSERVED WIND AT 1,000 M. ALTITUDE FOR THE YEAR 1905 (BERLIN AND LINDENBERG).

Table of Averages.

—	Theoretical Velocity V_0.	Velocity at 1,000 metres V.	Percentage difference between V_0 and V.	Mean deviation, in points, of V from V_0 [+ve when V veers from V_0].	Mean Surface Wind.	Mean deviation of Wind V from Surface Wind.	Surface Wind ÷ V_0 cos (Deviation).	Wind at 1,000 metres ÷ V_0 cos (Deviation).	Component wind ⊥ to isobars at surface ÷ component at 1,000 metres.
				Berlin.		"points."			
Jan. ...	15·7 m.p.s.	15·1 m.p.s.	4	−0·6	5 m.p.s.	3·3	·45	·97	1·9
Feb. ...	12·0 „	11·6 „	3·5	−0·6	4 „	2·7	·41	·98	1·7
March ...	8·1 „	6·6 „	23	−0·4	2·6 „	1·7	·35	·82	1·9
				Lindenberg.					
April ...	10·2 m.p.s.	8·8 m.p.s.	16	−1·0	4·8 m.p.s.	1·7	·54	·90	1·4
May ...	8·3 „	6·5 „	28	−1·0	4·5 „	2·3	·65	·80	1·9
June ...	6·8 „	6·4 „	6	−0·5	3·9 „	1·1	·60	·95	1·9
July ...	8·4 „	8·2 „	2·4	−0·9	4·5 „	1·2	·58	1·0	1·3
August...	8·9 „	8·0 „	11	−0·9	5·1 „	1·6	·64	·92	1·6
Sept. ...	10·3 „	10·5 „	−2	−0·8	5·4 „	2·2	·63	1·03	1·6
Oct. ...	12·1 „	11·9 „	2	−0·5	6·3 „	2·7	·64	·99	2·7
Nov. ..	10·6 „	10·1 „	5	−0·9	5·9 „	3·1	·78	·97	2·3
Dec. ...	11·0 „	10·3 „	7	+0·3	5·5 „	3·9	·65	·94	−5·−?
Summer	8·8 m.p.s.	8·1 m.p.s.	8·5	−0·8	4·7 m.p.s.	1·7	—	·93	—
Winter...	11·6 „	10·9 „	6·5	−0·45	4·9 „	2·9	—	·95	—
Year ...	10·2 „	9·5 „	7·5	−0·6	4·8 „	2·3	—	·94	—

If instead of summer and winter we take the six months of greatest and six months of least velocities we get even more remarkable agreement in the months of high velocities, the averages being 11·9 and 11·6 for calculated and observed respectively. For the month of low velocities the corresponding numbers are 8·4 and 7·4.

The table also gives the mean deviation in points between the surface wind and the upper wind.

The table shows a distinct annual variation, the deviation in the winter months being three times that in summer. The upper wind on the average veers from the surface wind.

The table shows, too, the ratio between the velocity perpendicular to the isobars at the surface and at 1,000 metres. With the exception of December the figures indicate a tendency for the perpendicular velocity at the surface to be about 1·7 times that at 1,000 metres. The table indicates, however, that the ratio is larger in winter than in summer or that the inflow of air into the region within a closed isobar diminishes more rapidly with height in winter than in summer.

We give also the ratio of the observed surface wind to the resolved part of the theoretical wind in the direction of the surface wind.

In April the station was moved from Berlin to Lindenberg, and the change in the ratio is very marked. At present the wind values used for forecasting are those at the surface and it appears probable that practical use could be made of the theoretical wind by constructing factors for each station similar to the ratio here found.

The corresponding values for the upper wind are also given and show an approximation to unity.

In the case of straight isobars in which friction is acting, the steady state will be that in which there is equilibrium between the forces due to the pressure gradient and those corresponding to the friction and the Earth's rotation effects. If α is the inclination of the wind to the isobars and $F\sigma$ is the force due to friction and θ the latitude, this condition may be written $2\,\omega\,v\sin\theta : F : \frac{1}{\sigma}\frac{dp}{dn} = \cos\alpha : \sin\alpha : 1$. Now $\frac{1}{\sigma}\frac{dp}{dn} = 2\,\omega\,v_0\sin\theta$ where v_0 is the gradient velocity, therefore we ought to have $v = v_0\cos\alpha$. The table shows that this is not the case, and we conclude that at the surface the state of affairs does not persist long enough for a steady velocity, in accordance with the hypothesis, to be reached.

On the other hand the conclusion to be drawn for the upper air is that the currents in the free atmosphere have generally been in motion long enough to ensure their approximate steadiness and that the directions of the wind and the isobars in the free atmosphere are known when either is known.

Graphical Representation of Results obtained at Oxshott, Berlin, and Blue Hill.

During 1906 a regular series of kite ascents was made by W. H. Dines, F.R.S., at Oxshott, in connection with the Meteorological Office. The results were published each week in the Weekly Weather Report of the Meteorological Office. From the data given there, diagrams have been drawn to show the changes which took place in the various meteorological elements with varying height. The diagrams have been already published in a paper by Dr. Shaw, in the Aeronautical Journal, but for purposes of completeness they are reproduced here.

To obtain a concise graphical representation of the change with altitude, the value of each element at 500 metres altitude was taken as datum points for each ascent. In this way although we lose the relation between the changes and the absolute values, we eliminate the effect of surface variations, and obtain a clear idea of the changes in the upper strata.

The observations were divided into four groups corresponding to the quadrants from which the wind was blowing, a W. wind being counted in the S.W. quadrant, and so on for the others. After plotting in this way, the results for temperature were divided into four sections, according as the change was (1) greater than that corresponding to the adiabatic change for dry air; (2) between the adiabatic changes for dry and saturated air; (3) less than the adiabatic change for saturated air; (4) inverted.

The observations in each of these sections were averaged, and a line drawn in the direction of the average gradient, the thickness of the line being proportional to the number of observations in the section (Plate 1). The dotted lines represent the gradient for dry and saturated air ascending adiabatically. The diagrams show that in the first stratum the gradient tends to be slightly less than the dry adiabatic, except for S.E. winds, for which the average gradient in the first stage is nearer the saturated adiabatic.

There are a number of observations in which the gradient is greater than the adiabatic gradient for dry air. In such cases there must have been vigorous vertical motion.*

In the second stratum the gradient tends to the saturated adiabatic for southerly winds, and lies about midway between the two adiabatics for northerly winds. There are no gradients greater than the dry adiabatic in this stratum, but inversions occur.

In the next stratum the gradient for S.E. and N.W. winds is large, lying about midway between the two adiabatics, while the gradients for N.E. and S.W. winds are smaller on the whole than the saturated adiabatic.

Few observations were recorded at 2,000 metres, but those shown indicate a considerable diminution in the gradient for the stratum between 1,500 and 2,000 metres.

As observations taken at Berlin and Lindenberg in 1905 were relatively more frequent, each group was divided, according to the four seasons, into four sub-groups, the observations in which were divided into sections as for Oxshott. We thus get 16 diagrams (Plates 2 and 3) illustrating the temperature changes, and three more have been drawn to indicate the changes in individual observations taken when Berlin was near the centre of a cyclone or anticyclone.

Taking first the changes that occur in the first stratum we see that in winter the gradient is generally less than the saturated adiabatic for all winds except N.E., for which three ascents out of six gave gradients between the two adiabatics. The relative number of inversions is greater for Easterly winds than for Westerly. In Spring the gradient increases, and the observations on the whole give gradients between the two adiabatics, except for N.E. winds, which again shew a peculiarity, half the gradients clustering about the saturated adiabatic, the other half being greater than the dry adiabatic. Inversions are about half as frequent as in Winter.

In Summer, for S.W. winds the gradients are very irregular: out of 42 ascents, 11 give gradients greater than the dry adiabatic, 16 lie between the two adiabatics, 10 are less than the saturated adiabatics, and there are five inversions.

For N.W. winds there are no inversions, and the gradients congregate about the dry adiabatic.

For N.E. winds the same may be said, save that there are two inversions.

For S.E. winds the majority of the ascents give gradients greater than the dry adiabatic.

In Autumn, for S.W. and S.E. winds, the gradients exhibit similar features, being distributed among the four sections, but showing a tendency to congregate about the saturated adiabatic.

For N.W. winds there are again no inversions, but in other respects the gradients are similar to those for S. winds. For N.E. winds there are no gradients greater than the dry adiabatic, but the majority lie between the two adiabatics.

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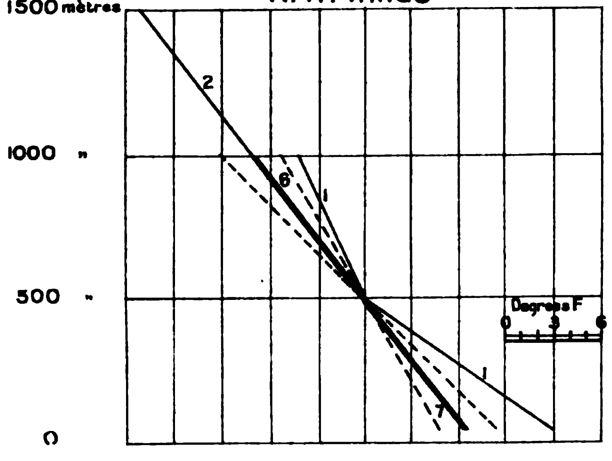
* The motion under these conditions has been worked out on certain assumptions by Guldberg and Mohn who find for a mean temperature excess in the warm column of 6° C., an upward velocity of 14 metres per second at a height of 1,000 metres. *See* Etudes sur les Mouvements de l'Atmosphere. Part II., p. 26.

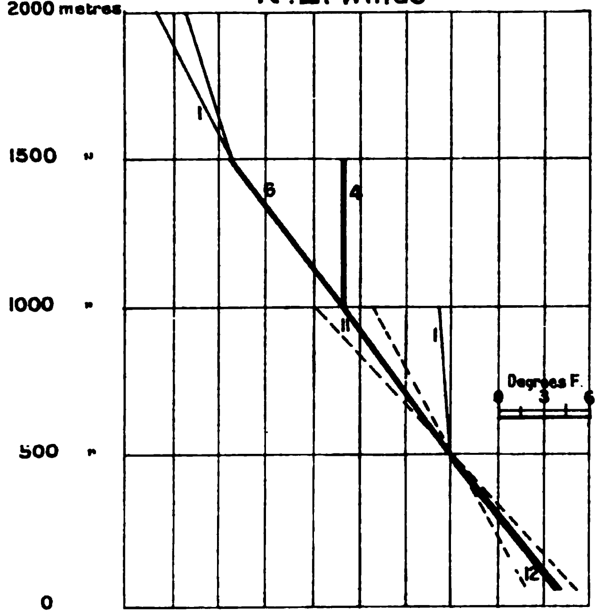
Plate 1.

TEMPERATURE
OXSHOTT

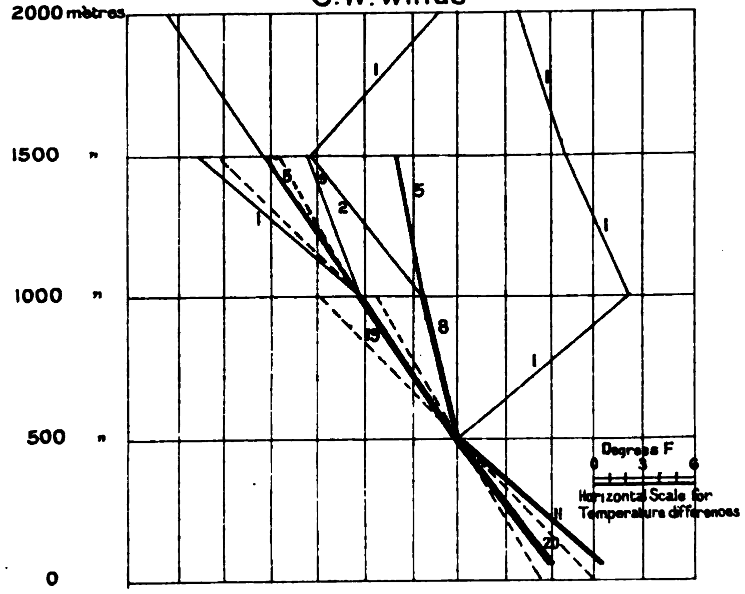
N.W. winds



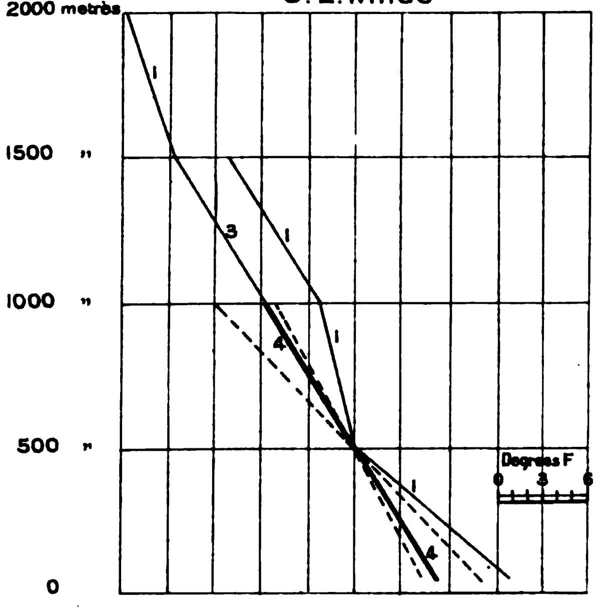
N.E. winds



S.W. winds



S.E. winds



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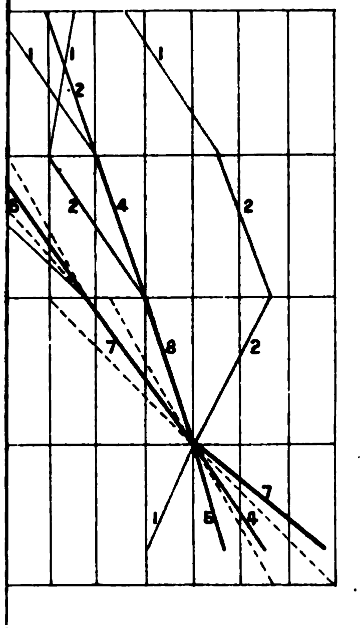
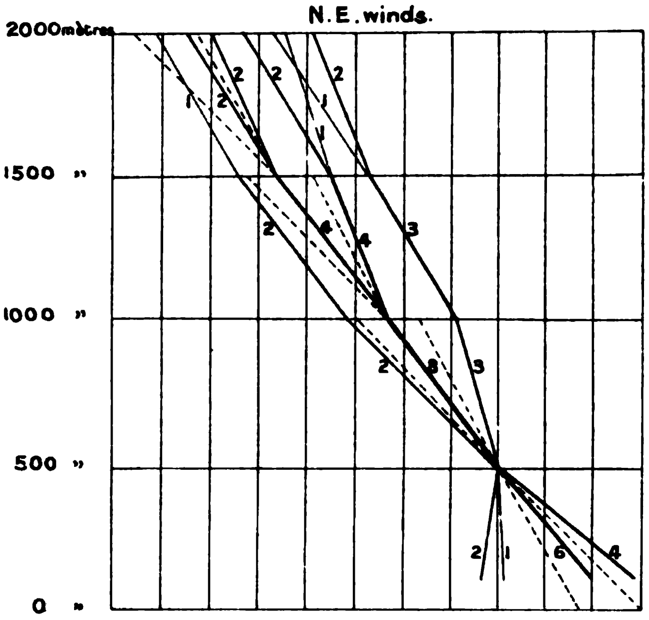
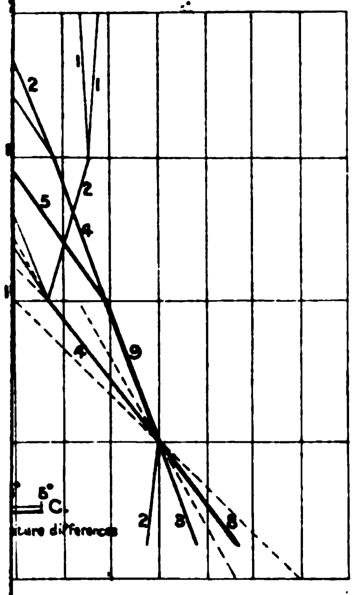
ND LINDENBERG
Apr., May, 1905
E. winds



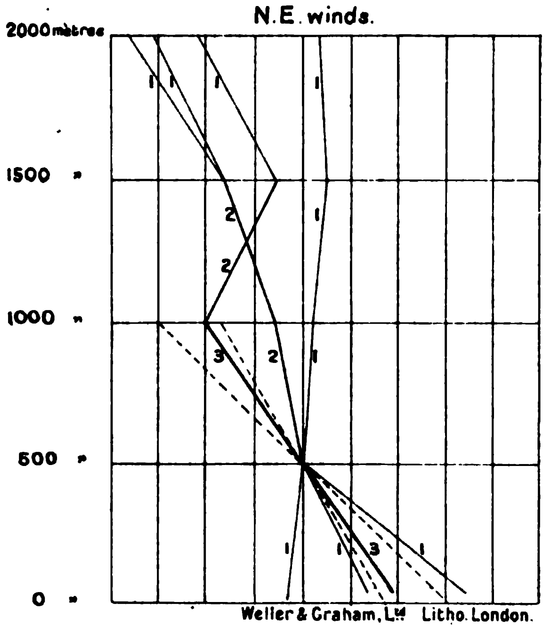
LINDENBERG.
June, July, Aug., 1905.
N.E. winds.



NDENBERG
, Oct., Nov., 1905.
N.E. winds.



BERLIN AND LINDENBERG
Dec., Jan., Feb., 1905.
N.E. winds.



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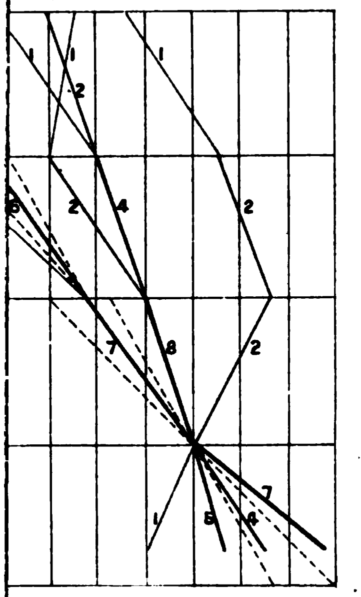
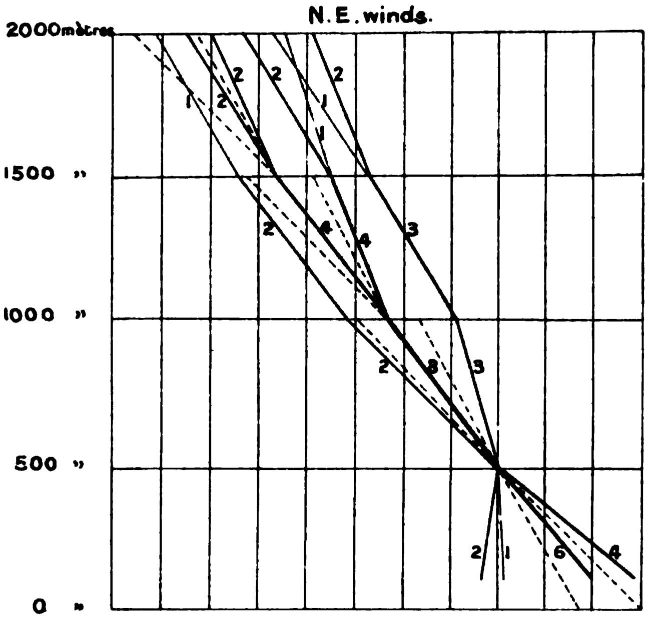


ND LINDENBERG
Apr., May., 1905
E. winds



LINDENBERG.
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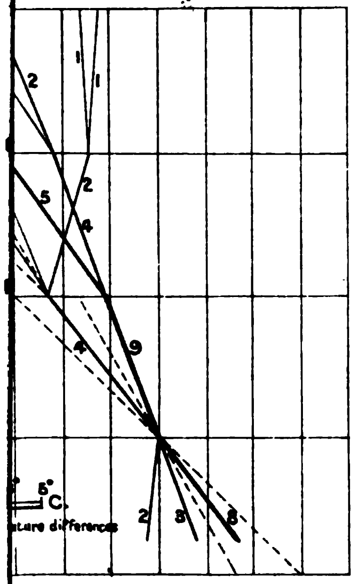
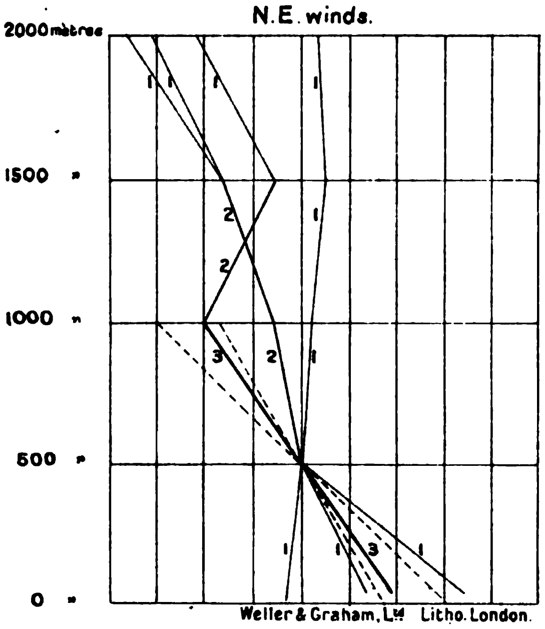
N.E. winds.



NDENBERG
Oct., Nov., 1905.
N.E. winds.



BERLIN AND LINDENBERG
Dec., Jan., Feb., 1905.
N.E. winds.

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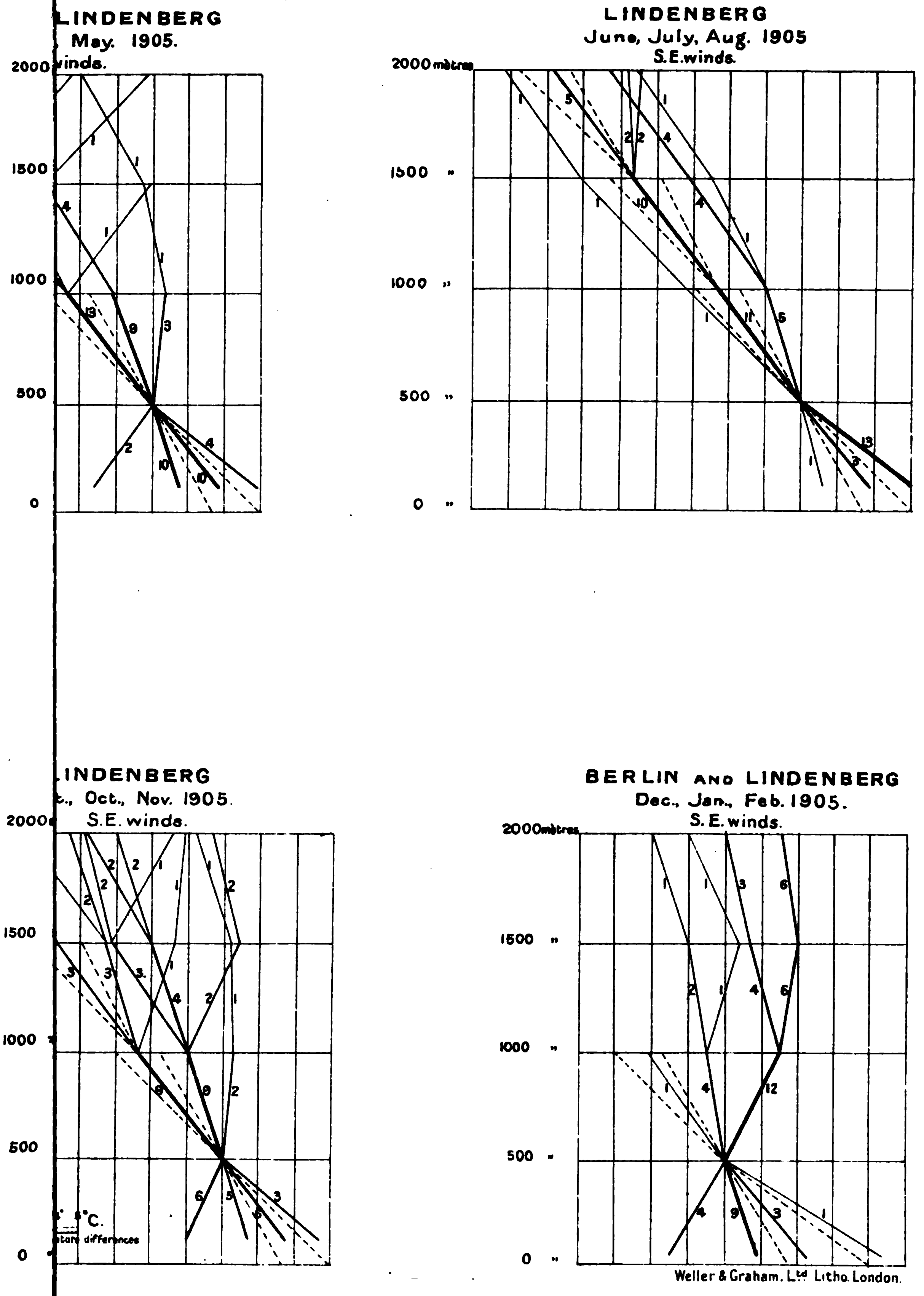
Plate 3.



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In general, for the first stage we may say that N.W. winds are marked by paucity of inversions, S.E. winds by frequency of inversions in autumn and winter, and of large gradients in summer, N.E. winds by relatively large gradients in winter and inversions in summer, and S.W. winds by frequency of inversions in autumn and small gradients in winter.

Taking the second stratum, we see that in winter the prominent phenomenon is the frequency of inversion with S.E. winds. N.E. winds show a larger gradient than the others, and on the whole the distribution is similar to that in the first stage. In spring there are no inversions with S. winds, while the number with N. winds increases. There are no cases of gradient greater than the dry adiabatic. S.W. winds give gradients least scattered, and N.W. winds gradients most scattered if inversions are left out.

For Summer there are no inversions, and the general trend of the gradient is toward the direction midway between the adiabatics, except for N.W. winds, which give more gradients less than the saturated adiabatic. In all groups, except the N.W. one, gradients greater than the dry adiabatic occur.

In Autumn inversions occur with S. winds, but not with N.; the general tendency is for a similarity of gradient to that in the first stage, except for N.E. winds, which give $\frac{2}{3}$ of the gradients less than the saturated adiabatic.

In general, in the second stage, we may say that N.W. winds are marked by large gradients in spring and autumn, and small gradients in summer and winter; S.E. winds by frequency of inversions, especially in winter; N.E. winds by large summer and winter gradients, and small gradients in autumn and spring, together with inversions in spring and none in autumn, while S.W. winds are mainly characterised by the similarity between the gradients in the first and second stages.

Taking the third stage, the winter is characterised by the comparative uniformity of temperature for Easterly winds, there being about as many increases as decreases of temperature. N.W. winds are remarkable as showing not a single temperature inversion, and a grouping of the results about the saturated adiabatic: S.W. winds show a similar grouping, but comparatively frequent inversions.

In Spring, the gradients are larger in general for Easterly than for Westerly winds: two inversions only occur, both in South winds.

In Summer, the gradients are fairly regular, and there are no inversions except for N.W. winds, for which also there is one case of a gradient greater than the dry adiabatic.

In Autumn, inversions recur especially with S. winds: there are none with N.W. winds. The gradients, apart from inversions, show greater scattering with Easterly winds.

In general, in the third stage the gradients for N.W. winds are marked by great regularity except in Summer: for S.E. winds by regularity in Summer and irregularity in Spring and Autumn and the average constancy in Winter: for N.E. winds by regularity especially in Summer and by average constancy in Winter: for S.W. winds by regularity in Spring and Summer and divergence in Autumn and Winter.

Taking the fourth stratum, in Winter for S.E. winds there is a very slight downward gradient: northerly winds show an average gradient between the two adiabatics: S.W. winds show a small average gradient and the single inversion that occurs.

In Spring, the gradient for westerly winds is remarkably regular and there are no inversions: Easterly winds show three inversions, but apart from this the gradient is larger than for Westerly winds.

In Summer, inversions occur for S.E. winds only, and apart from these the winds in this gradient give comparatively large gradients: in the remaining quadrants the gradient is regular.

In Autumn, the gradients for Westerly winds are regular and show no inversions: for Easterly winds there is greater scattering and three inversions.

In general, in the fourth stratum the gradients for N.W. winds show great regularity throughout the year : those for S.E. winds show inversions in every season except winter, when, however, the gradient is very small : those for N.E. winds are fairly regular in Summer and Winter, but show inversions in Spring and Autumn : S.W. winds show exceptional regularity except in Winter.

Looking at the diagrams together one is struck by the small average departure from the saturated adiabatic gradient, for Westerly winds in Spring and for N.W. winds in Autumn.

The spread of the diagrams for S. winds in Autumn contrasted with the narrow limits of confinement for the same winds in Spring is also remarkable : Spring in fact is the season when the vertical temperature gradient most nearly approaches regularity from the surface upwards.

The uniformity of temperature for Easterly winds in Winter has been already noted, as well as the absence of inversions in N.W. winds, except in Summer, when the few inversions in the upper strata occur for winds in this gradient.

The frequency of inversions for S.E. winds in Winter may be accounted for by the fact that the wind generally veers three to four points between the surface and 1,000 metres. The surface winds would, therefore, be more northerly than those above, and so on the average would come from a region of intenser cold.

Taking now the diagrams illustrating the vertical temperature gradient near the centres of low and high pressure systems, we see that for cyclones (Plate 4) the gradient in the upper strata is always very nearly that corresponding to saturated adiabatic change.

For anticyclones (Plates 5 and 6) it was necessary to divide the results into two groups corresponding to the cold and warm seasons. The gradients in the cold season show no sort of uniformity in the lower layers ; over 1,500 metres the tendency is to approach a mean between the dry and saturated adiabatic gradients. This diagram, in fact, gives direct evidence against any considerable descent of air near the centre of an anticyclone in Winter, at least to below 1,500 metres. In Summer, on the contrary, the lower strata show the most regular gradients, and the greatest percentage of irregularities occurs over 1,500 metres ; apart from these, the gradient is very regular and very slightly less than the dry adiabatic.

The results obtained from observations taken in manned balloons show a gradient very nearly equal to the saturated adiabatic in the upper strata. The gradient nearer the surface varies with the surface temperature in such a way that the temperature at 5,000 metres varies very slightly for the different ascents.

The following table was constructed to indicate the way the temperature gradient between the ground and 1,000 metres changed with the surface temperature :—

No. of Observations.	Ground Temperature 122 metres level.		Temperature at 1,000 metres.		
	Range.	Average.	Range.	Average.	Average Change.
	° C.	° C.	°	°	° C.
2	−15 to −10	−12·1	−15·4 to −13·6	−14·5	−2·4
9	−10 „ − 5	− 6·3	−11·5 „ − 1·6	− 6·3	0·0
30	− 5 „ 0	− 1·8	−11·0 „ 4·8	− 4·0	−2·2
106	0 „ 5	2·3	− 6·2 „ 7·2	− 1·0	−3·3
58	5 „ 10	7·3	− 2·7 „ 9·5	2·2	−5·1
67	10 „ 15	12·9	2·0 „ 12·0	7·2	−5·7
76	15 „ 20	17·3	5·1 „ 16·7	10·9	−6·4
32	20 „ 25	22·4	11·0 „ 18·9	14·8	−7·6
7	25 „ 30	26·4	14·3 „ 22·0	19·0	−7·4
2	over 30	30·5	20·4 „ 23·5	22·0	−8·5

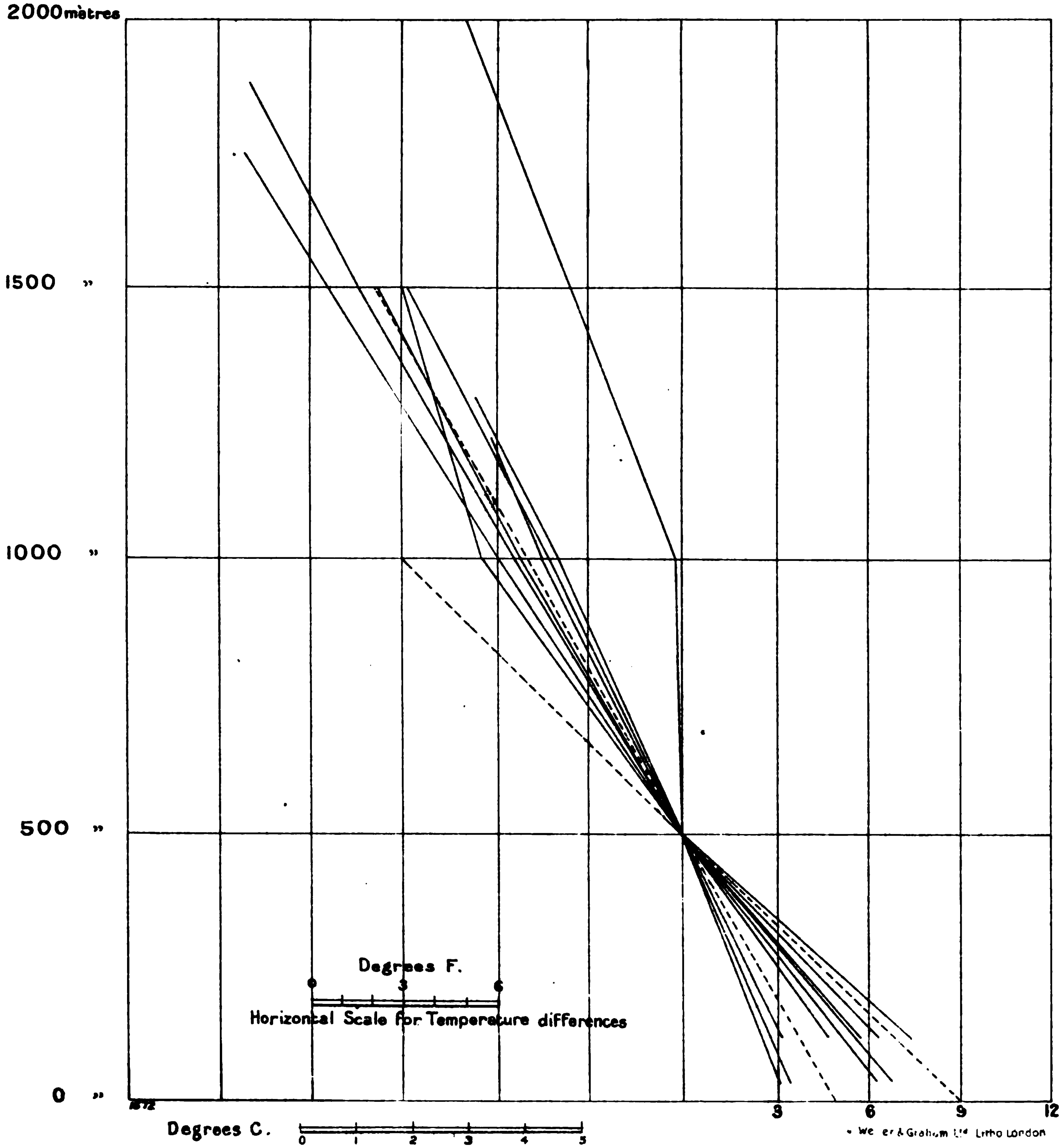
These numbers show a tendency to approximate to 9° the gradient corresponding to the adiabatic change for dry air.

Plate 4.

BERLIN AND LINDENBERG.

Temperature gradient near the centre of cyclonic systems.

Jan. 7, Mar. 28, Apr. 3, 6, 21, May 20,
July 19, Aug. 30, Oct. 6, Dec. 30.



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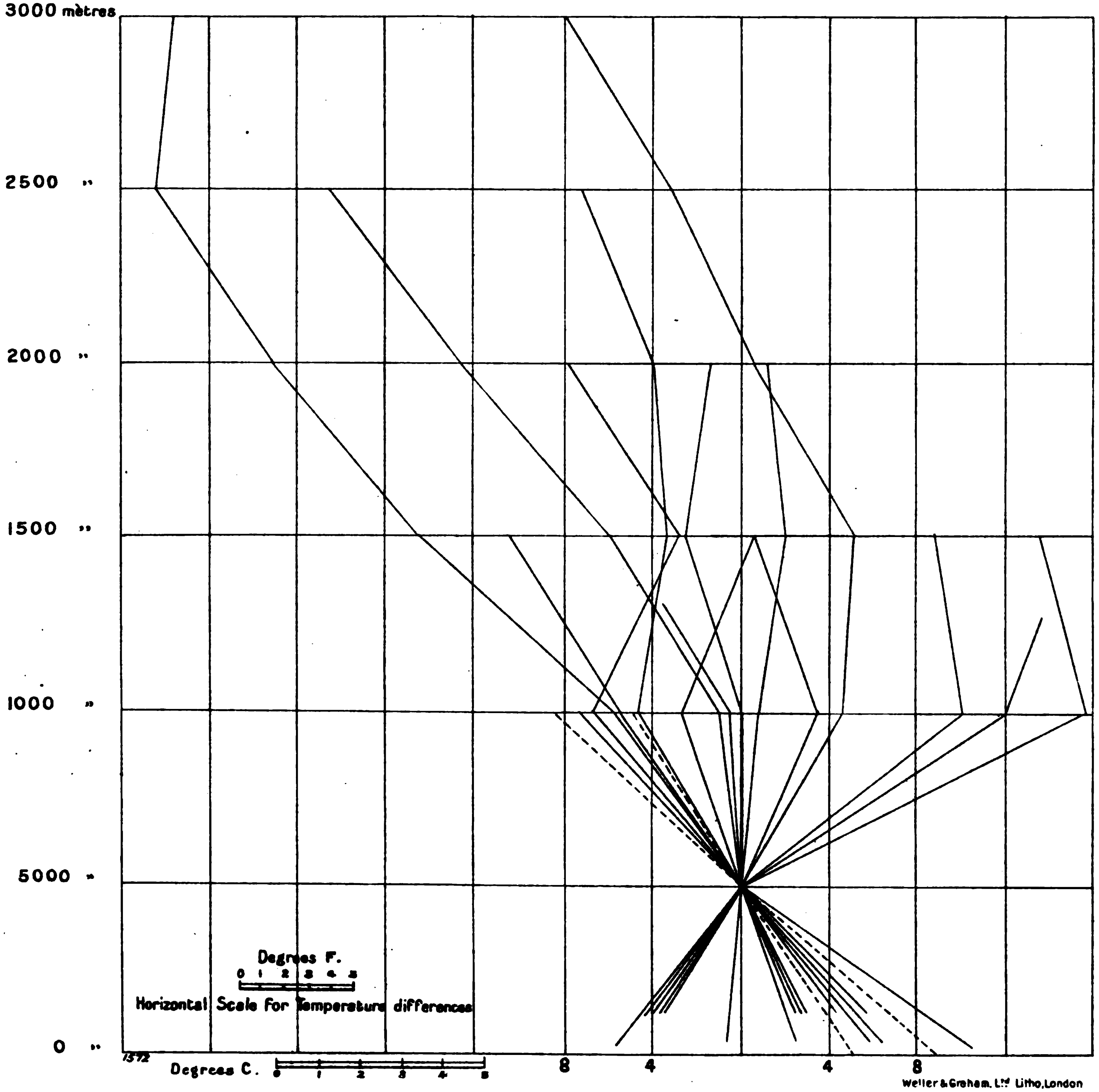
BERLIN AND LINDENBERG.

Temperature gradient near the centre of Anticyclones

Winter



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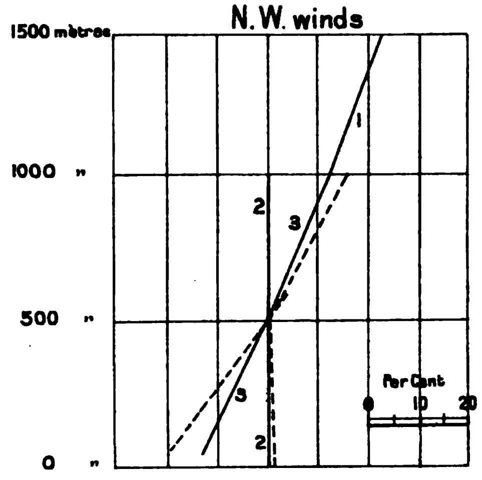
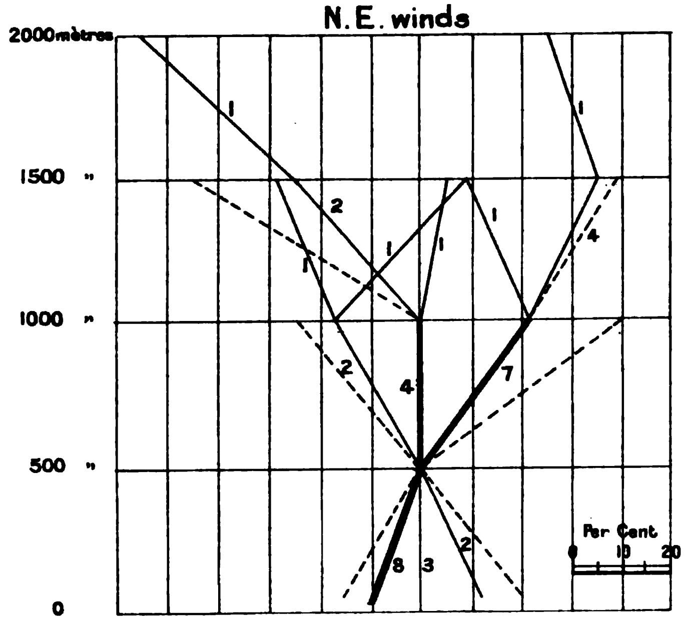
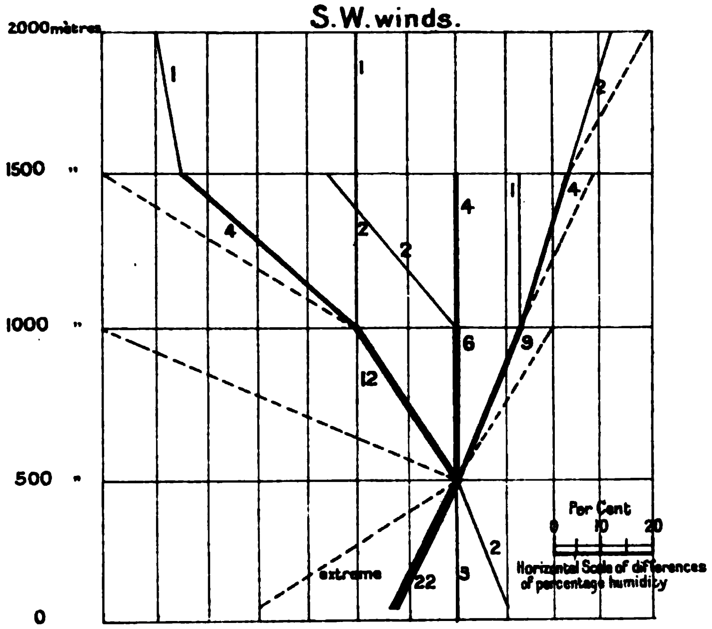
HUMIDITY
OXSHOTT

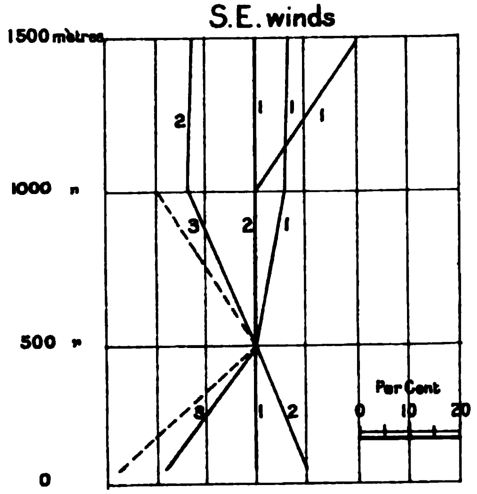




Dotted lines show extreme variations



Horizontal Scale of differences of percentage humidity



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1672

RATIO $\frac{\text{MASS OF VAPOUR}}{\text{MASS OF AIR}}$ PER CUBIC METRE

OXSHOTT

N.W. winds.

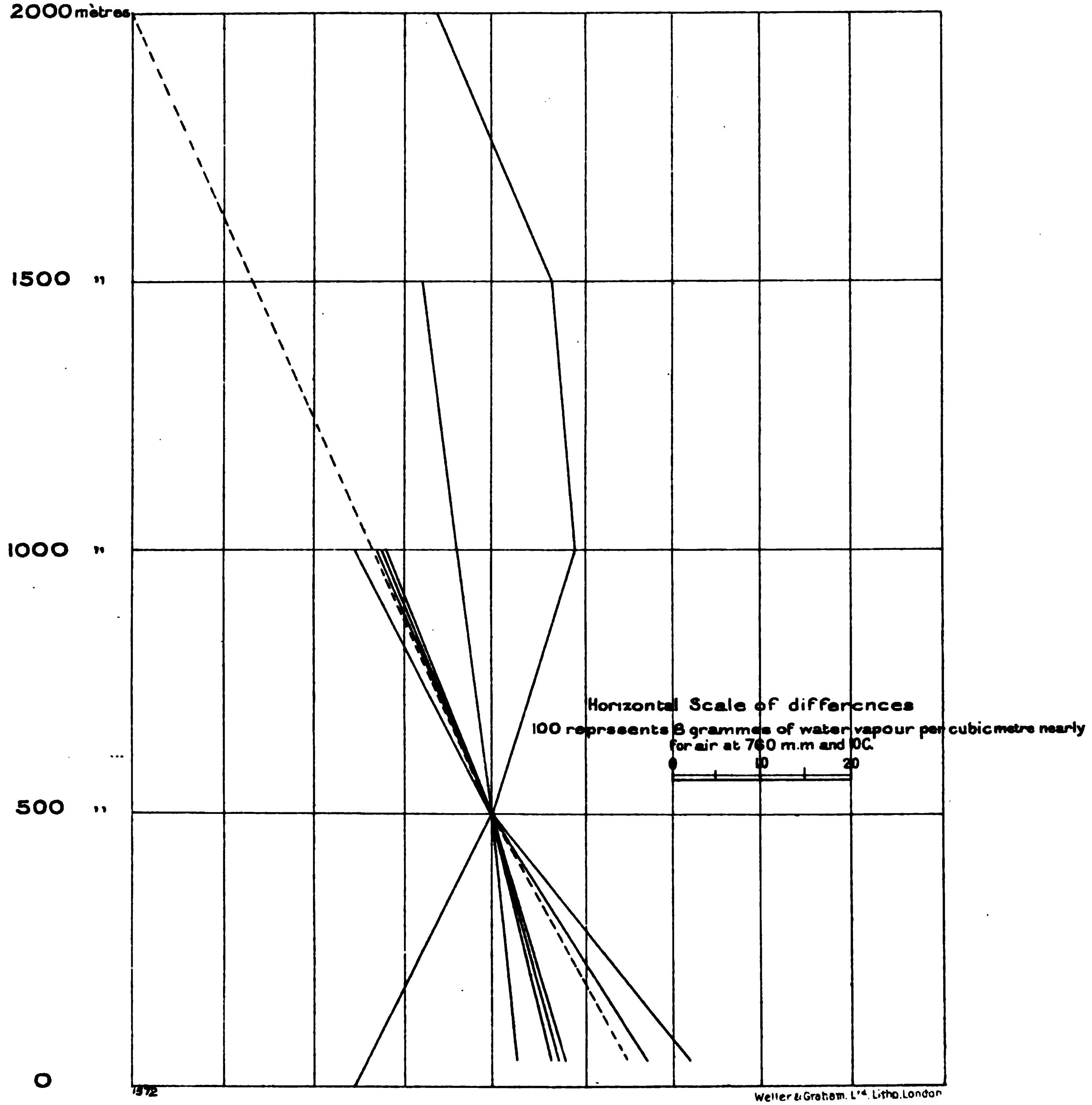
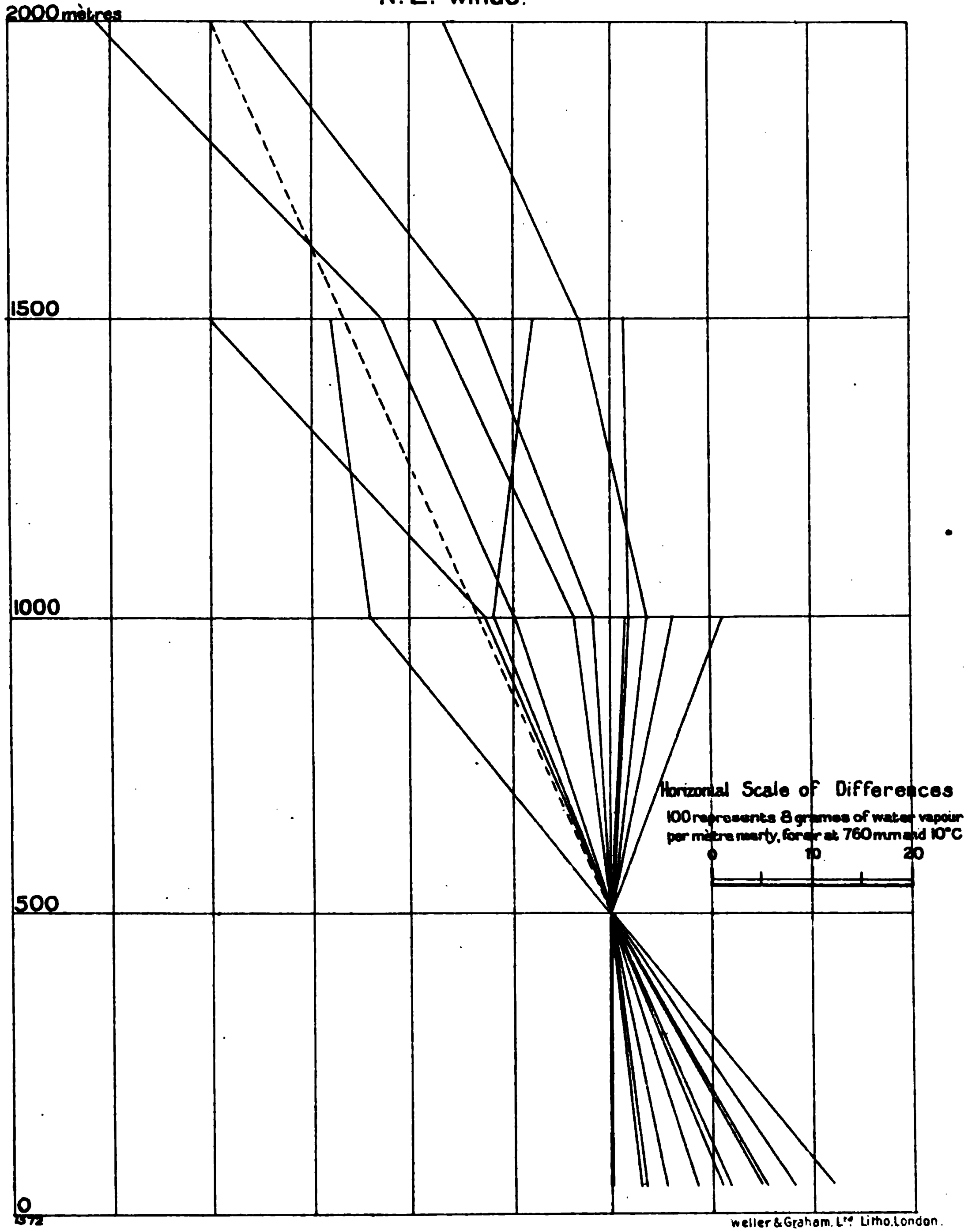


Plate 9.

RATIO $\frac{\text{MASS OF VAPOUR}}{\text{MASS OF AIR}}$ PER CUBIC METRE

OXSHOTT

N.E. winds.



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RATIO $\frac{\text{MASS OF VAPOUR}}{\text{MASS OF AIR}}$ PER CUBIC METRE

OXSHOTT

S.W. winds

The dotted line shows how the ratio would change
with saturation from the beginning and adiabatic
temperature gradient, the temperature being 5°C at 500 mètres

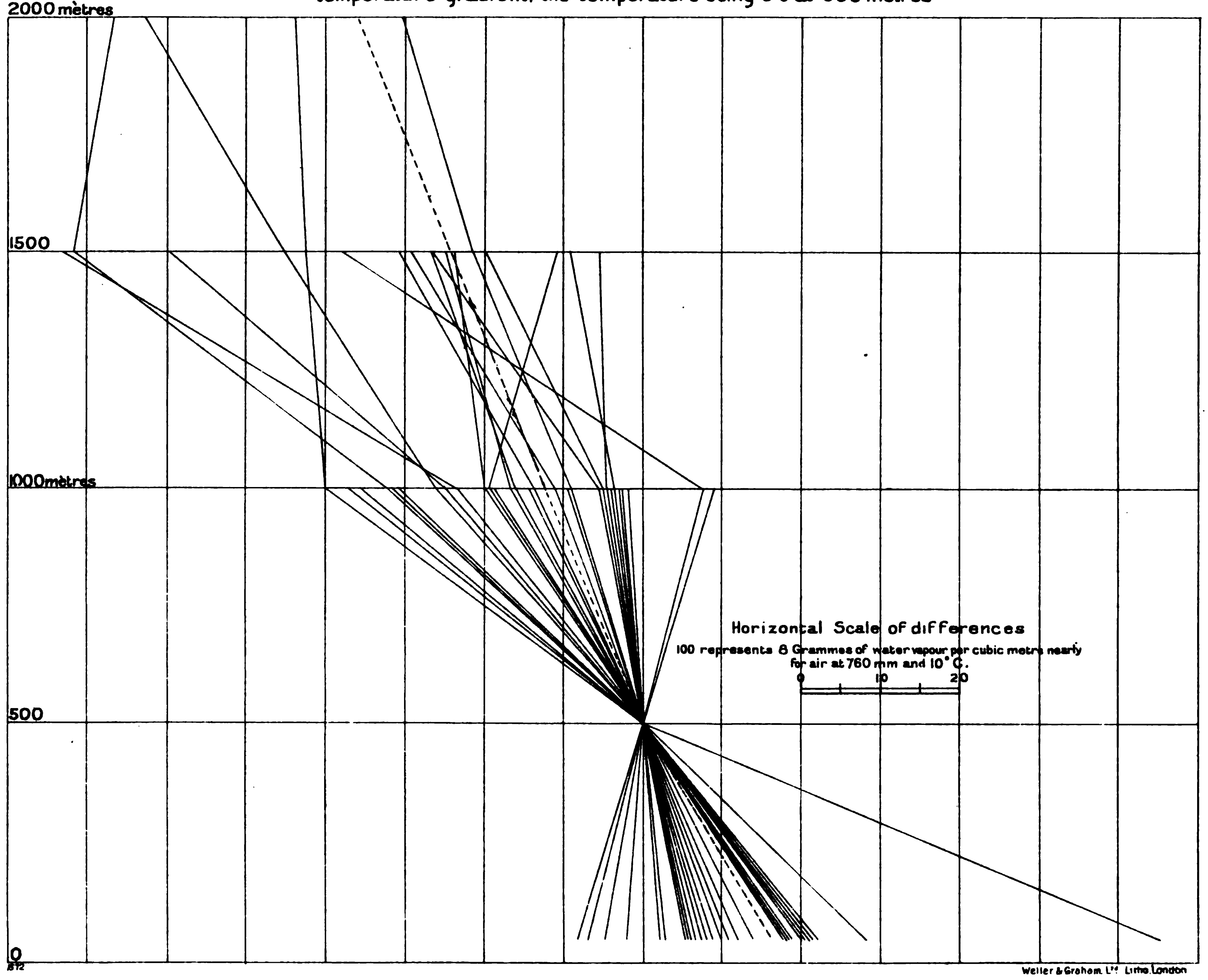

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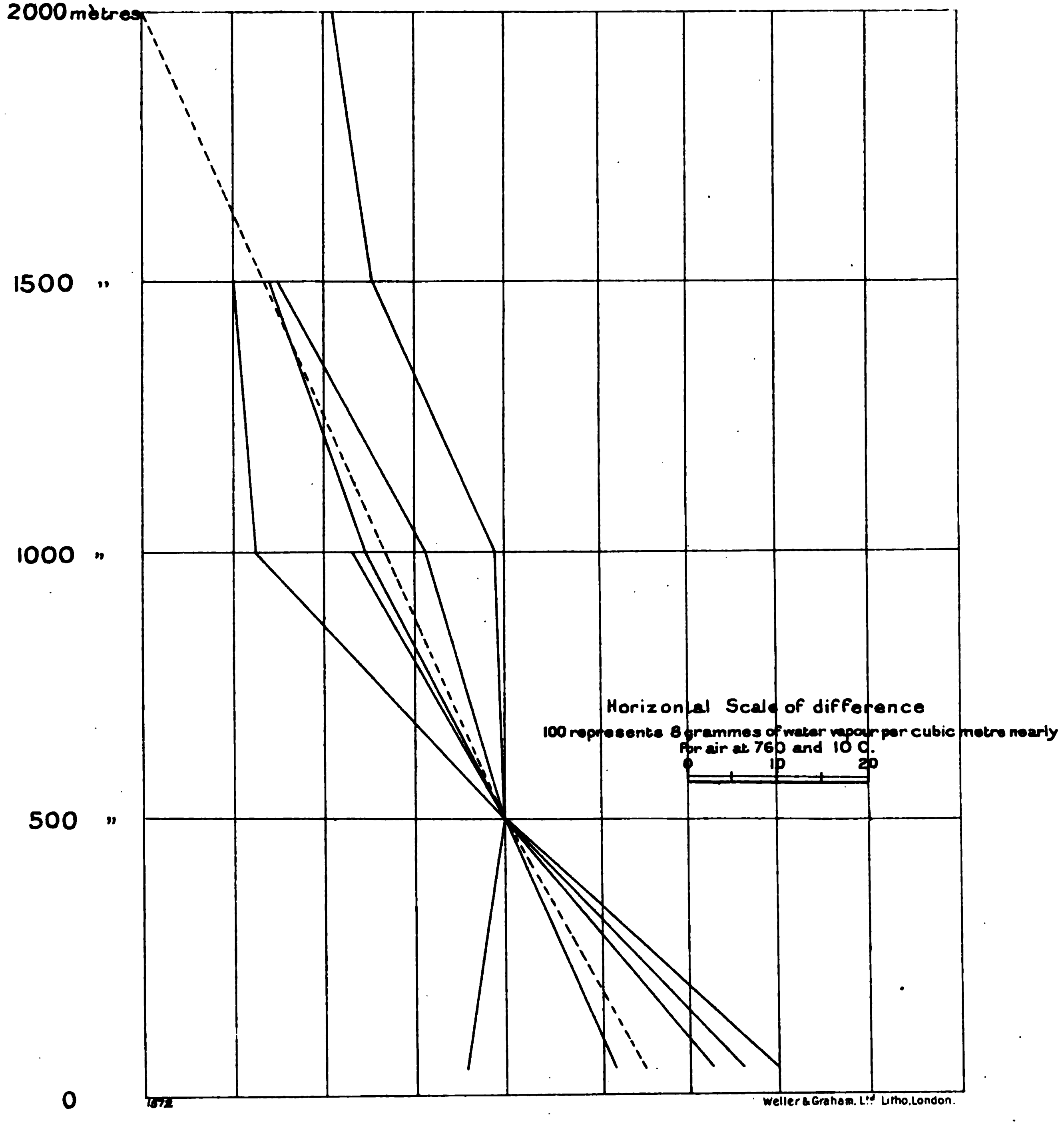
Plate 11

RATIO $\frac{\text{MASS OF VAPOUR}}{\text{MASS OF AIR}}$ PER CUBIC METRE

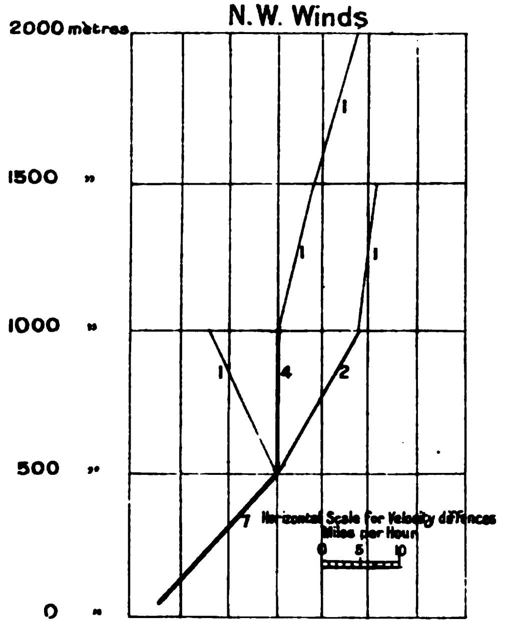
OXSHOTT

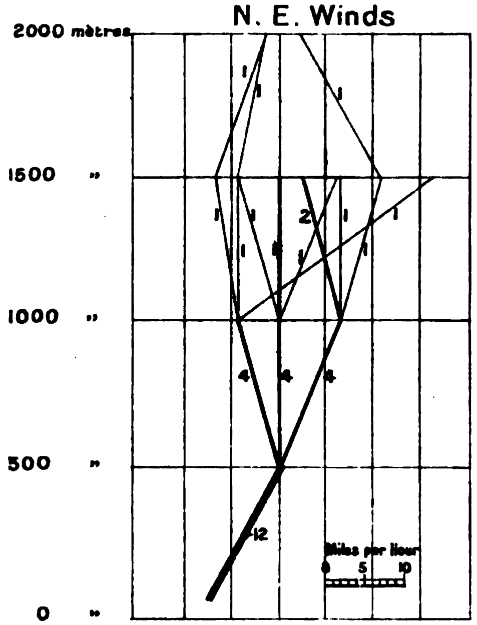
S.E. winds

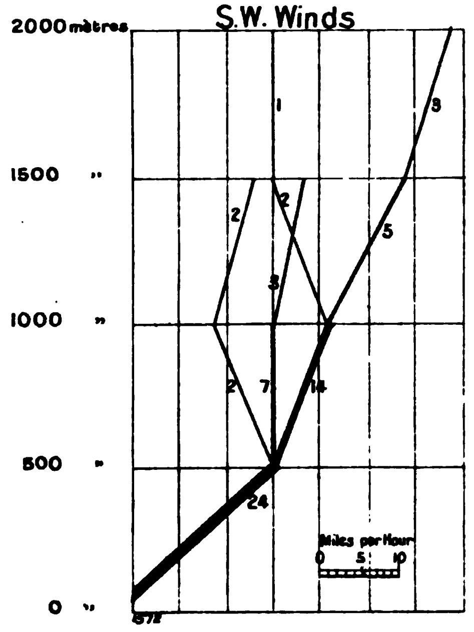
The dotted line shows how the ratio would change with saturation from the beginning and adiabatic temperature gradient, the temperature being 5°C at 500 mètres.



WIND VELOCITY
OXSHOTT


N.W. Winds


N. E. Winds


S.W. Winds

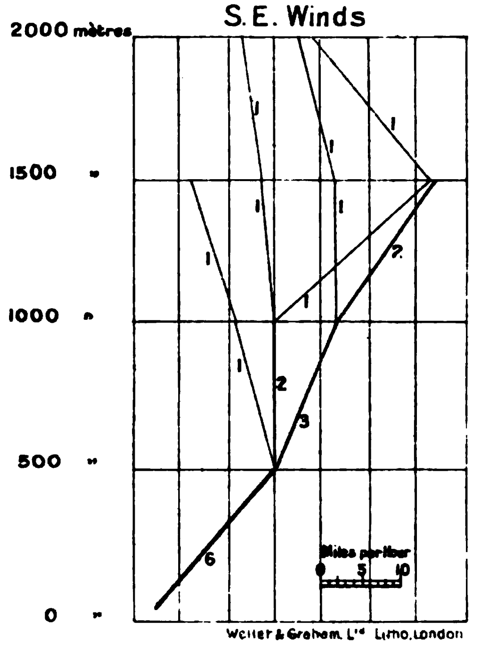

S.E. Winds

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Plate 12.

WINDS
BLUE HILL
1903 – 04
All Winds.

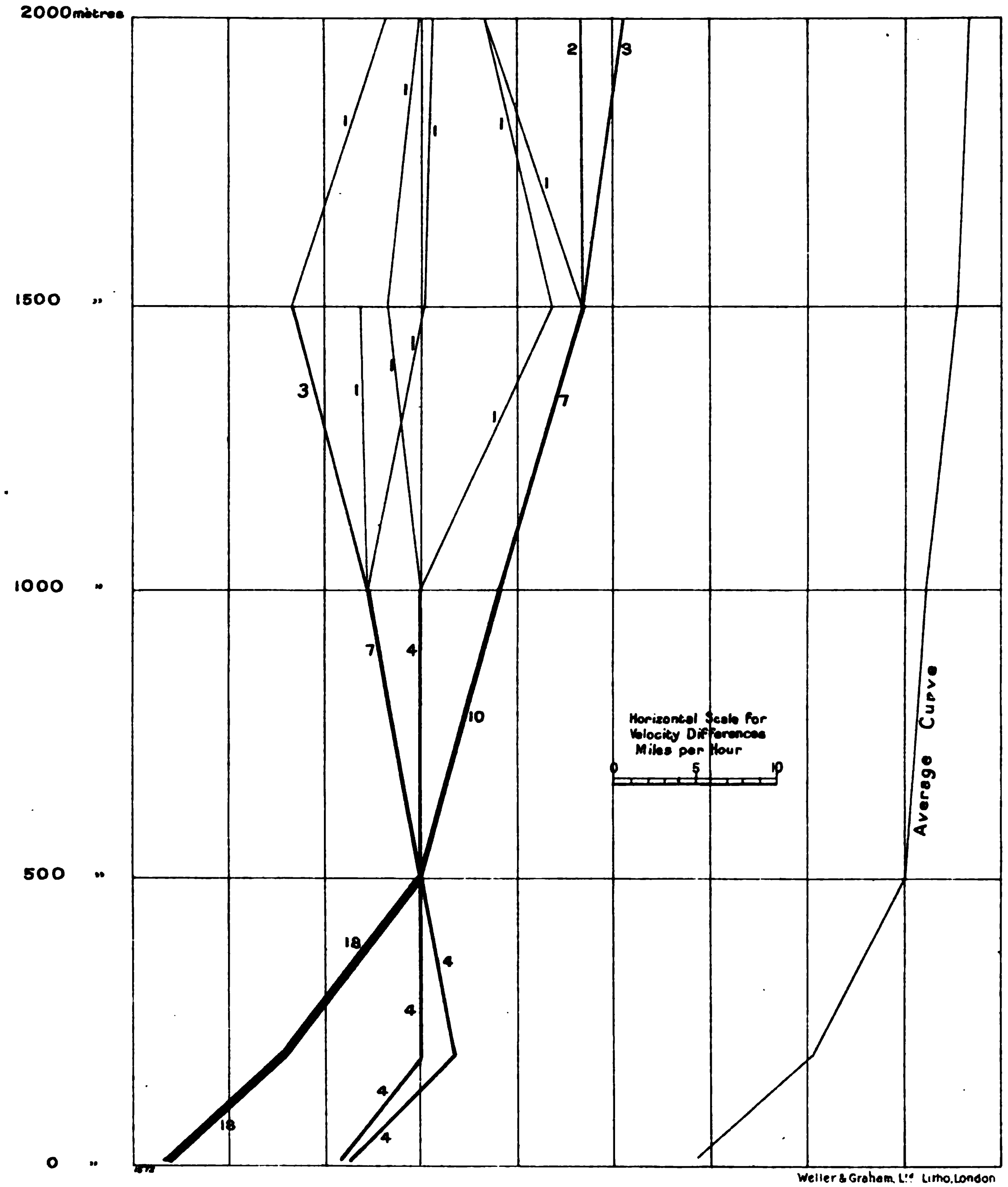

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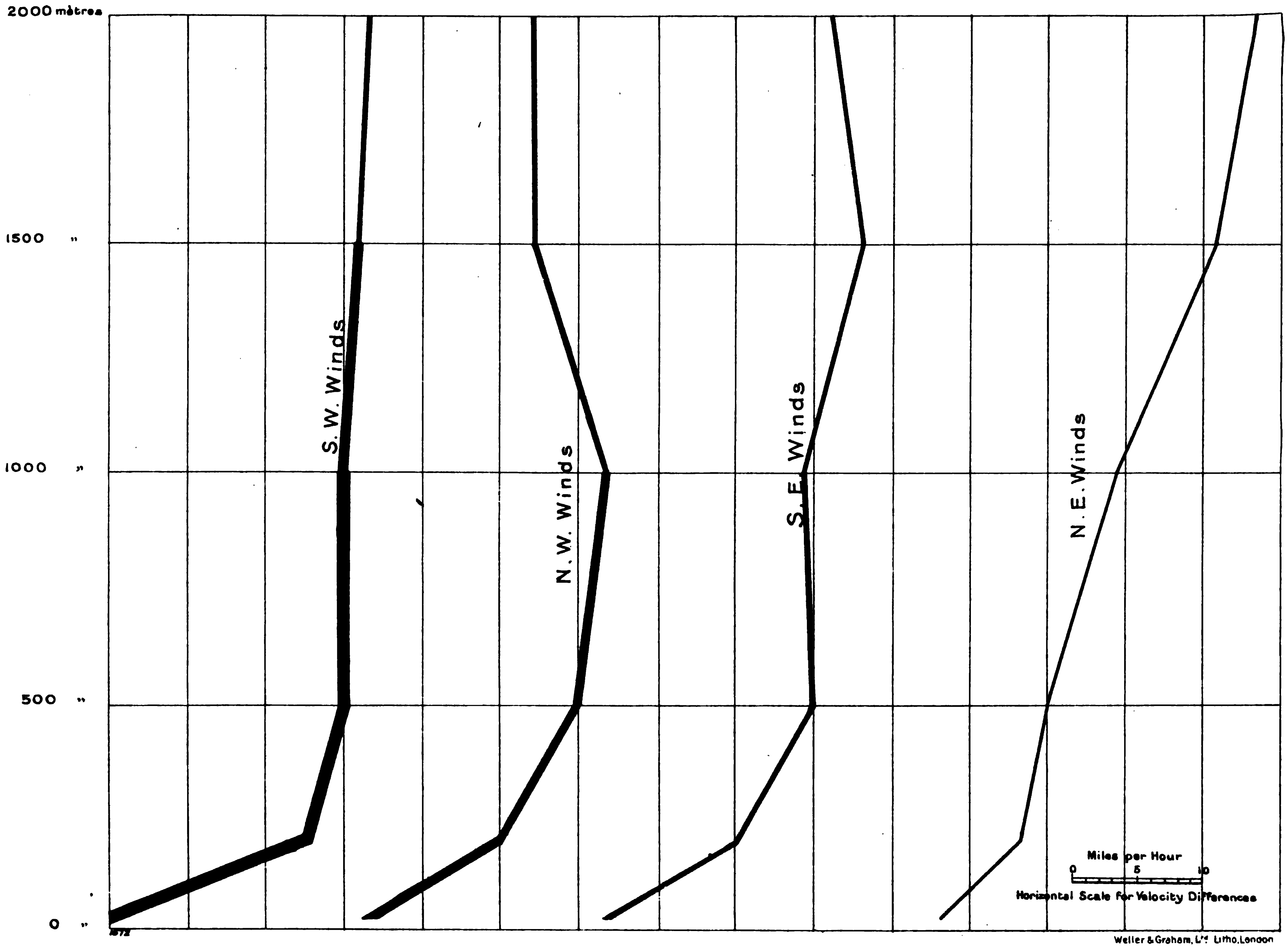
Plate 13.

Plate 14.

BERLIN — Winter 1905.

Change of Wind Velocity with Height. Variations from Values at 500 mètres.



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Diagrams were drawn from the data obtained from the Oxshott ascents, to illustrate the change of humidity with height. The diagrams first drawn (Plate 7) were those for the relative humidity, and, as will be seen, they show no sort of tendency to obey any law, the relative humidity as frequently increasing as diminishing with altitude, except for the few results obtained with N.E. winds, in all of which the humidity increased with altitude. If the air at the upper levels were the same as that at the surface, except for vapour lost by rain, the relative humidity would in all cases increase with altitude or remain constant.

To see if there was any indication of a congregation about the two critical cases, the ratio of the mass of water vapour to that of air at each stage was calculated from the observations. The ratio at 500 metres was taken as datum point and the differences plotted. For air ascending without change of constitution the ratio would be constant until saturation point was reached. Afterwards the ratio would change in the manner indicated approximately by the dotted line. It will be seen (Plates 8, 9, 10, 11) that there is a tendency to congregate about these directions, especially in the second stratum.

Diagrams were also drawn to illustrate the change of wind velocity with height. The diagrams for Oxshott (Plate 12) show that for all winds there is a relatively large increase between the surface and 500 metres, altitude, but that for the higher strata the changes are small and irregular. For N.W. winds there is an average increase of 12 miles per hour between the surface and 500 metres. Between 500 and 1,000 metres the change is very small, but on the whole there is a slight increase. In the ascents above 1,000 metres, the wind increased steadily at the rate of about a mile per hour per hundred metres. For N.E. winds the average increase in the first stage was nine miles per hour; the average increase in the next stage was less than one mile per hour. In the third stage there occurs one case of an increase of 25 miles per hour, but apart from that there is a slight decrease. In the fourth stage the average increase is practically zero.

For S.W. winds there is an average increase of 18 miles per hour in the velocity at 500 metres; an average increase of about 3½ miles per hour in the second stage, and slightly less in the third stage, while in the fourth stage the average increase was 4½ miles per hour.

For S.E. winds the average increase in the first stage was 16 miles per hour; between 500 and 1,000 metres the velocity increased on the average by about three miles per hour; in the 3rd stage the increase was about four miles per hour, but every ascent which reached 2,000 metres gave a diminution in the fourth stage.

The results of the observations made at Blue Hill, U.S.A., were also taken, and the diagram (Plate 13) shows that the velocity continues to increase, in the majority of cases, up to 2,000 metres altitude, though the rate of increase diminishes with altitude and is less than two miles per hour per 500 metres after the 500-metre level is passed.

During January and February, 1905, the wind velocities at Berlin were published for the altitude of 200 metres as well as for each 500 metres. These results have been averaged and the diagrams (Plate 14) show the result. The greater part of the increase for all winds takes place between ground level (40 metres above m.s.l.) and 200 metres, but the relative increases depend largely on the wind direction. S.W. winds on the average increase in velocity 15 miles per hour between the surface and 200 metres, and three miles per hour in the next 300 metres. Between 500 and 1,000 metres they are constant, and in the next two stages increase very slightly.

N.W. winds increase only 10 miles per hour in the first stage, and six miles per hour between 200 and 500 metres. They increase two miles per hour in the next 500 metres, and then diminish five miles per hour, remaining constant in the last stage.

S.E. winds increase also 10 miles per hour from the surface to 200 metres, and 5½ miles per hour between 200 and 500 metres. They diminish slightly in the next stage, then increase about four miles per hour, diminishing in the last stage by about three miles per hour. There is, therefore, a similarity of effect in N.W. and S.E. winds above 500 metres, the one increasing where the other diminishes.

For N.E. winds the velocity increases by six miles per hour at 200 metres, and by two only between 200 and 500 metres. In the next three stages the velocity continues to increase fairly rapidly, so that at 2,000 metres it is on the average 16 miles per hour greater than at 500 metres.

Now, N.E. winds in the winter of 1905 were such that the isotherms and isobars were approximately in the same direction, and, consequently, an increase of velocity with height would be expected unless the vertical temperature gradient differed materially across the isobars.

It will be seen by an inspection of the results (*see* Table VIII.), that for N.E. winds in winter the observed velocity at 1,000 metres was nearly always in excess of the gradient velocity corresponding to the surface gradient.

We conclude from these results that, on the average, the wind velocity reaches its maximum value asymptotically, but does not vary considerably from 500 metres upwards. The direction, however, frequently continues to change, veering from the surface wind to the gradient wind and reaching this at about 1,000 metres.

In conclusion I wish to express my thanks to Miss E. Humphreys, of the Meteorological Office, for help in constructing the diagrams, and to Mr. E. L. Ardley, of the Instruments Branch, for assistance in the numerical calculations.

NOTE ON THE RELATION OF THE CURVATURE OF THE ISOBAR TO THE CURVATURE OF THE PATH.

The curvature of the isobars is not the same as the curvature of the path of the moving air unless the pressure system remains for some time unchanged. This is not in general the case, but if the centre of curvature of the isobars moves in a known way we can calculate the curvature of the path from the velocity in the path and the curvature of the isobars.

Let r be the radius from the centre to the point under consideration, α the angle between this radius and the path of the centre measured in a counter-clockwise direction, v the velocity of the moving air, V that of the centre, and x, y the co-ordinates of the air under consideration.

Then, if the direction of the moving air make an $<$ θ with the tangent to the isobars, we have

$$\frac{dx}{dt} = -v \sin(\alpha + \theta)$$

$$\frac{dy}{dt} = v \cos(\alpha + \theta).$$

We shall regard θ as constant and v, α as depending on t. We get, therefore,

$$\frac{d^2x}{dt^2} = -v\cos(\alpha+\theta)\frac{d\alpha}{dt} - \sin(\alpha+\theta)\frac{dv}{dt}$$

$$\frac{d^2y}{dt^2} = -v\sin(\alpha+\theta)\frac{d\alpha}{dt} + \cos(\alpha+\theta)\frac{dv}{dt}.$$

The radius of curvature of the path is equal to

$$\frac{\left\{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2\right\}^{\frac{3}{2}}}{\frac{dx}{dt}\frac{d^2y}{dt^2} - \frac{dy}{dt}\frac{d^2x}{dt^2}}$$

and this is equal to $\dfrac{v}{\frac{d\alpha}{dt}}$.

But now $r\,d\alpha = v\,dt\cos\theta + \mathrm{V}\,dt\sin\alpha$,

$$\therefore \frac{d\alpha}{dt} = \frac{v\cos\theta + \mathrm{V}\sin\alpha}{r}$$

$\therefore$ the radius of curvature ρ is given by

$$\rho = r\frac{v}{v\cos\theta + \mathrm{V}\sin\alpha} = r\frac{1}{\cos\theta + k\sin\alpha} \text{ where } k = \frac{\mathrm{V}}{v}.$$

In the case of motion tangential to the isobars, this gives $\rho = \frac{r}{1 + k \sin \alpha}$ and $\rho > r$ for all points to the right hand of the path of the centre and $\rho < r$ for all points on the left of this line, for cyclonic motions. In anticyclonic motions these directions are reversed.

The value of k may be as big as $\frac{1}{2}$ or even bigger for a rapidly moving cyclone, and the difference in the resulting correction to be applied would be very considerable for points near $\alpha = \frac{3\pi}{2}$.

Thus, a straight isobar velocity of 40 m.p.s. at a point on an isobar where the angular radius of the oculating circle was 2° would be reduced, in such a case, to 26·2 m.p.s. instead of to 21·4 at $\alpha = \frac{3\pi}{2}$ and to about 18·4 m.p.s. for $\alpha = \frac{\pi}{2}$.

Such differences are large enough to serve as a basis for the determination of the motion of the centre from observed values of the upper air velocity and the pressure distribution. Thus, qualitatively, a theoretical value, deduced according to the tables given in the preceding pages, that was lower than the observed value would indicate the point of observation to be to the right of the line of motion of the centre, while, if the theoretical value was too high the point would be to the left of the line of motion for cyclonic systems, and conversely for anticyclonic.

Taking as an example the 7th January, 1905, we deduce from the pressure distribution and observation that the radius of curvature to bring about the appropriate correction is 8°. We have also, by observation, $\theta = 22\frac{1}{2}°$ and $\cos \theta = \cdot 93$.

We get, therefore, $8\,(\cdot 93 + k \sin \alpha) = 5$, or $k \sin \alpha = -\cdot 31$, or putting $k = \frac{V}{25}$ we get $V \sin \alpha = -7{\cdot}7$. If we had a similar observation at one other place we should have two equations to determine V and the direction of motion.

There are, of course, other factors which may cause departure from the theoretical velocity, such as variation in vertical temperature gradient, or a rapid pressure change in which steadiness of motion is not reached. It is hoped in a further investigation of the relation between observed and theoretical values to test this relation for actual cases.

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